

Chapter 8: Overview of Ten ANALYTICA[®] Models

8.1 Introduction

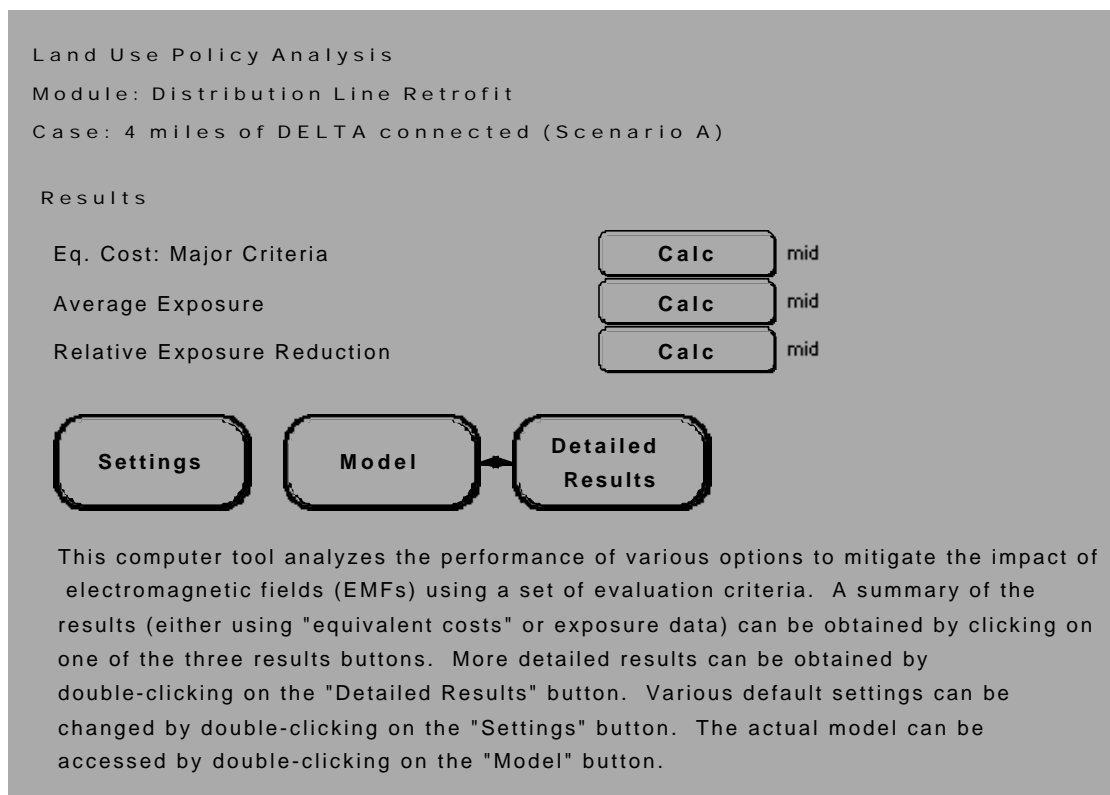
This chapter describes the decision analysis models that were generated for the various EMF sources discussed in Chapter 3. These models were implemented in ANALYTICA[®], a decision analysis software package distributed by Lumina Decision Systems (Lumina Decision Systems, 1997; see also their web site at www.lumina.com). This section will first briefly outline the main components of each of the models, before each individual model is described in some detail. Models were generated for the following scenarios (filenames are given in parentheses):

1. Transmission Line Retrofit – 69 kV (TR-69.ana);
2. Transmission Line Retrofit – 115 kV (TR-115.ana);
3. Transmission Line Retrofit – 230 kV (TR-230.ana);
4. New Transmission Line – Scenario A (TN-115-A.ana);
5. New Transmission Line – Scenario B (TN-115-B.ana);
6. New Transmission Line – Scenario C (TN-115-C.ana);
7. Distribution Line Retrofit – Scenario A (DR-A.ana);
8. Distribution Line Retrofit – Scenario B (DR-B.ana);
9. Home Grounding – Scenario A (HOME-A.ana);
10. Home Grounding – Scenario B (HOME-B.ana).

These scenarios were chosen to cover a broad spectrum of EMF sources, mitigation options and land use assumptions. For example, the “New Transmission Line – Scenario A” analyzes three possible routes for the new line in addition to three possible line configurations (resulting in nine alternatives), whereas “New Transmission Line – Scenario B” analyzes the effects of different ROWs for one route and three line configurations. For each scenario, the list of possible alternatives (see Table 3.4) was screened to eliminate unreasonable line configurations and other impractical alternatives (e.g., increasing the ROW where houses exist). Thus, each model concentrates on the analysis of the most promising mitigation options.

While the specific alternatives of each model are different for the reasons just described, each model uses the same overall framework to analyze and the same objectives to evaluate these alternatives. This framework and the development of the objectives were described in detail in Chapter 3, which emphasized the continuous involvement and input of the Stakeholder Advisory Committee. We will now outline how this framework and the evaluation criteria (including the necessary tradeoffs between competing criteria) were implemented in each ANALYTICA[®] model. A detailed description of the individual parts of an ANALYTICA[®] model is found in Appendix A.

1 The opening screen (shown in Figure 8.1) allows the user to see an overview of
2 the results (including relative exposure reductions of the various alternatives) and to
3 access the other sub-modules in the ANALYTICA[®] model. These sub-modules basically
4 follow a hierarchical design that specifies individual model components in more and
5 more detail. For example, Figure 8.2 shows how the user can define the main input
6 parameters (e.g., specifying the physical layout of the particular scenario, including
7 population characteristics, land use assumptions, etc.) using the “Settings” screen.



8 **Figure 8.1: Opening Screen of an ANALYTICA[®] Model**

Exposure - Hazard Assumptions		Cost Specification	
Risk Ratios	Edit Table	Choose: TPC Sources	Enertec ▼
Base Rates	Edit Table	TPC per Mile (User-Defined)	Edit Table
Maximum Risk Ratios	Edit Table	Fixed TPC (User-Defined)	Edit Table
Degree of Certainty: Hazard	Edit Table	Choose Scenario: O&M	Mediu ▼
Probability (Metric)	Edit Table	Total Annual O&M Cost (per Mile)	Edit Table
Tradeoffs			
Equivalent Cost	Edit Table		
Assumptions about Outages		Impact on Property Values	
Average Outage Duration	Edit Table	Relative EMF Impact (Immediate)	Edit Table
Average Number of Interrupted Customers	Edit Table	Relative Non-EMF Impact (Immediate)	Edit Table
Percent of Outages Leading to Interruptions	Edit Table	Relative EMF Impact (Research Known)	Edit Table
		Average Property Value (Dollars)	Edit Table
		Choose Reference Point	Switch ▼
Scenario Choices			

Figure 8.2: The “Settings” Screen in an ANALYTICA^â Model

The screen shown in Figure 8.3 shows the main components of the decision analysis framework described in Chapter 3 (e.g., alternatives, criteria, tradeoffs, sensitivity analyses, results) and the link to the exposure calculations from the Effects Functions approach described in Chapter 4. By accessing the “Criteria” node, the users will see the list of ends objectives used to evaluate the alternatives in each model. For each criterion, the user can then access the details of how the consequences are modeled and calculated (see Figure 8.4).

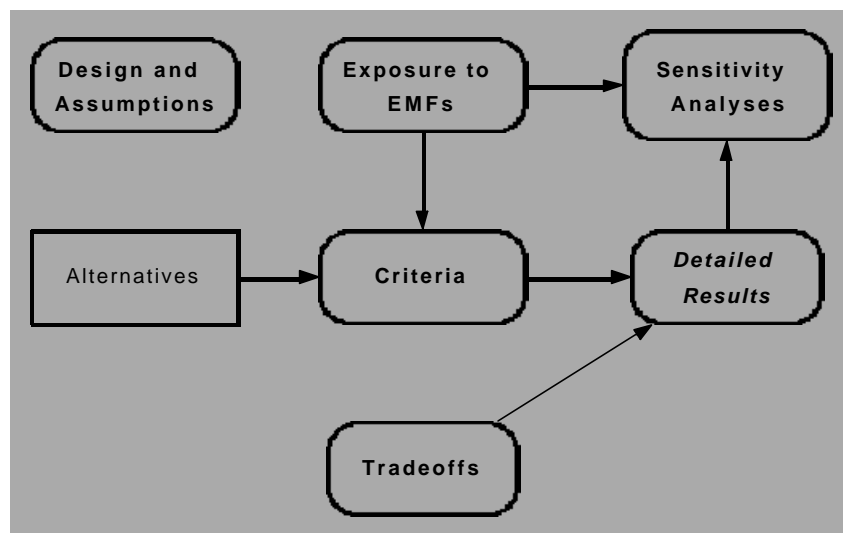


Figure 8.3: The Model Components in ANALYTICA^â

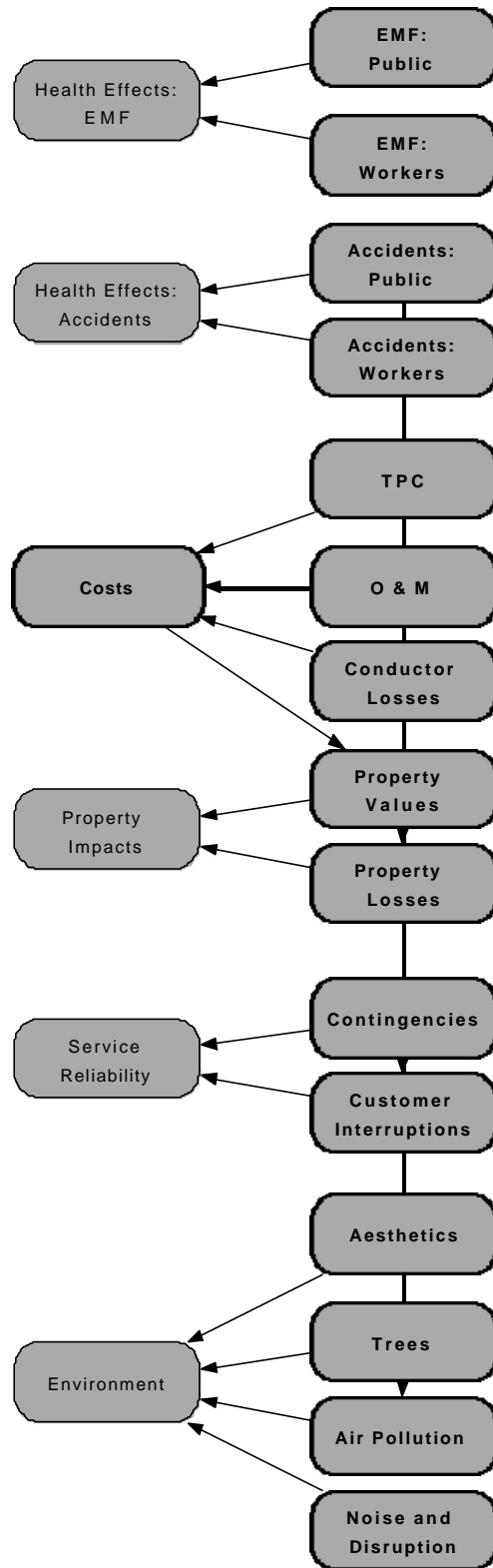


Figure 8.4: The Ends Objectives in each ANALYTICA^â Model

For example, Figure 8.5 shows how the risk calculations explained in Chapter 5 were implemented in the ANALYTICA[®] models (using the calculation of fatal brain cancers among adults as an example).

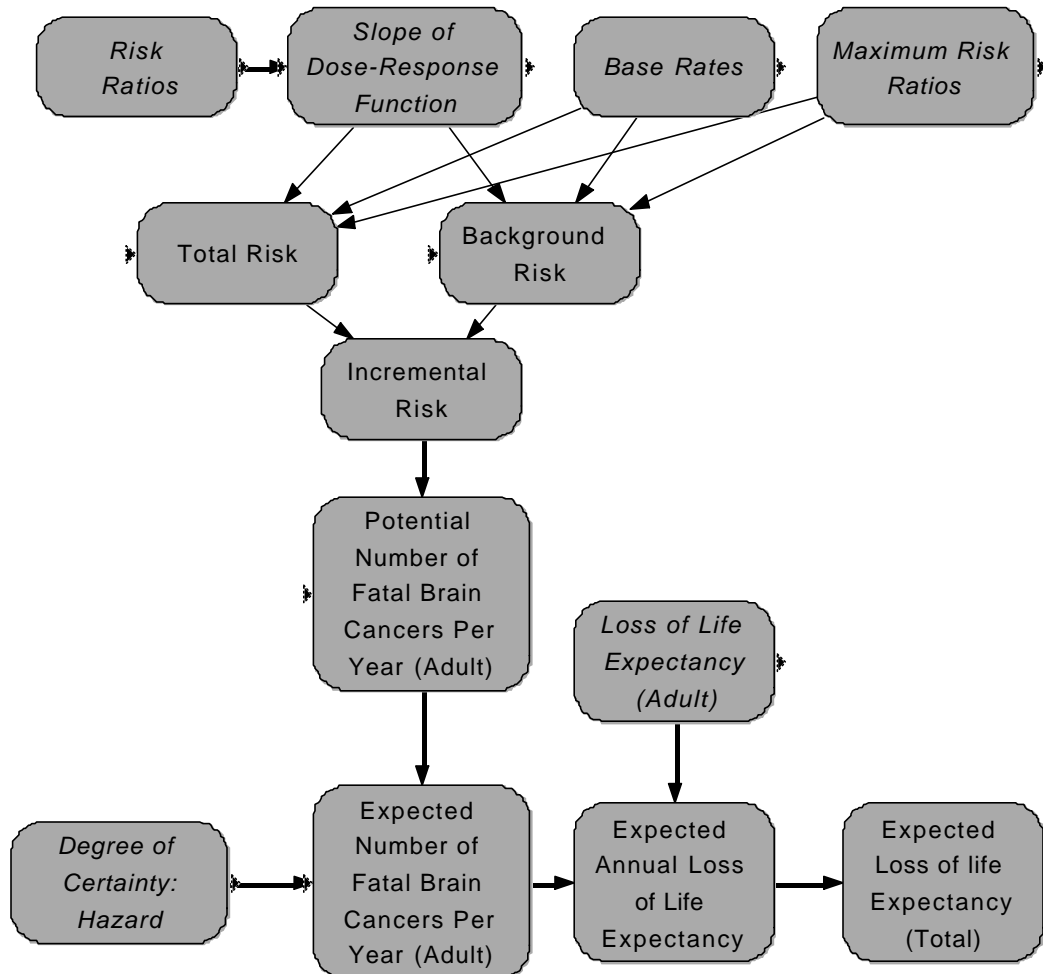


Figure 8.5: Calculation of Consequences on a Health Endpoint (Illustration)

Finally, the user can access and change the tradeoffs that each model assumes to evaluate the overall performance of the considered alternatives on the set of criteria. These tradeoffs are given as “Equivalent Costs,” defined for units of all criteria in the model, in order to make the consequences on different criteria commensurable. An overview of the default unit equivalent cost is given in Table 8.1. The literature on the value of life and injuries was used to define default values for criteria involving mortality and morbidity (see, for example, Jones-Lee, 1976; Thaler and Rosen, 1975; Howard, 1980; Viscusi, 1992, 1993; Tengs et al., 1995). In addition, a recent interview with five national researchers familiar with the risk tradeoff literature (Keeney and von

1 Winterfeldt, 1997) was used to calibrate the tradeoffs. Other values were estimated based
2 on common sense reasoning.

3 **Table 8.1: Default Equivalent Cost in the ANALYTICA^a Models**

Consequence	Equivalent Cost
One Year of Life-Expectancy Lost:	\$100,000
One Non-Fatal Cancer (Adult):	\$300,000
One Non-Fatal Cancer (Child):	\$500,000
One Alzheimer's Disease:	\$200,000
One Serious Injury:	\$10,000
One Contingency Hour:	\$10,000
One Person-Hour of Electricity Disruption:	\$10
One Pole Collision (Property Damage):	\$10,000
One Lost Tree:	\$1,000
One Person-Day of Noise and Disruption:	\$10
One Unit on Aesthetics Scale:	\$10,000

4 With these unit tradeoffs, the overall equivalent cost of each alternative can be
5 calculated to determine the best alternative in each scenario. Furthermore, the models
6 allow to divide these overall equivalent cost into the major components and run various
7 sensitivity analyses that show how these costs would change if different assumptions are
8 made (for example about the EMF – Health Risk relationship).

9 **8.2 Default Values**

10 This section lists the default values for all models. General assumptions are listed
11 first. The other default values are organized by the main criteria of the model.

12 ***General:***

Variable	Default Value
Time horizon	35 years
Loss of life expectancy for adult fatalities	35 years
Loss of life expectancy for childhood fatalities	70 years
Loss of life expectancy for worker fatalities	40 years
Total miles of OH lines in CA	363,000 miles
Total miles of UG lines in CA	100,000 miles
Average household size	3
Population of California	30,000,000

Health Effects: EMF

Exposure Metrics

The exposure data were generated using Jack Adams' Effects Function (EF) simulation software. Exposures were calculated for the following exposure metrics:

- Time Weighted Average (TWA);
- Linear Threshold at 2 mG (LT2);
- Linear Threshold at 5 mG (LT5);
- Linear Threshold at 10 mG (LT10);
- Binary Threshold at 2 mG (BT2);
- Binary Threshold at 5 mG (BT 5);
- Binary Threshold at 10 mG (BT10).

By default, each model uses the TWA exposure metric.

Characteristics of Dose Response Function (TWA and linear thresholds)

Health Endpoint	Emed	RR(Emed)	RRmax
Adult brain cancer	2mG	2	5
Adult leukemia	2mG	2	5
Adult breast cancer	2mG	2	5
Alzheimer's disease	2mG	2	5
Childhood brain cancer	2mG	2	5
Childhood leukemia	2mG	2	5

Notes: Emed is the exposure at which the risk ratio is defined; RR(Emed) is the risk ratio at Emed; RRmax is the maximum risk ratio.

Characteristics of Dose-Response Function (Binary Thresholds- BT)

Health Endpoint	Emed				
	BT at 2mG	BT at 5mG	BT at 10mG	RR(Emed)	RRmax
Adult brain cancer	50%	20%	10%	2	5
Adult leukemia	50%	20%	10%	2	5
Adult breast cancer	50%	20%	10%	2	5
Alzheimer's Disease	50%	20%	10%	2	5
Childhood brain cancer	50%	20%	10%	2	5
Childhood leukemia	50%	20%	10%	2	5

Notes: Emed is the exposure at which the risk ratio is defined; RR(Emed) is the risk ratio at Emed; RRmax is the maximum risk ratio.

1 *Degree of Certainty: Hazard and Base Rates*

Health Endpoint	Degree of Certainty: Hazard	Base Rate
Adult brain cancer – fatal	0.1	Age Specific
Adult brain cancer – nonfatal	0.1	Age Specific
Adult leukemia – fatal	0.1	Age Specific
Adult leukemia – nonfatal	0.1	Age Specific
Adult breast cancer – fatal	0.1	Age Specific
Adult breast cancer – nonfatal	0.1	Age Specific
Alzheimer's disease	0.1	Age Specific
Childhood brain cancer – fatal	0.1	Age Specific
Childhood brain cancer – nonfatal	0.1	Age Specific
Childhood leukemia – fatal	0.1	Age Specific
Childhood leukemia - nonfatal	0.1	Age Specific

2 *Exposure for workers:*

Exposure Metric	Line Type	
	Overhead	Underground
TWA	2mG	4mG
Binary threshold at 2mG	50%	100%
Binary threshold at 5mG	25%	50%
Binary threshold at 10mG	10%	20%

3 *Number of worker-years per mile:*

4 Transmission lines: 0.0001

5 Distribution lines: 0.003

6 *Accidents - Public*

7 Total annual fire fatalities in CA: 319

8 Percent of fatalities due to OH lines: 5%

9 Total annual fire injuries in CA: 5,000

10 Percent of injuries due to OH lines: 5%

11 Total annual fatalities from collisions with utility poles in CA: 69

12 Percent of utility poles that are electrical utility poles: 90%

13 Number of poles per mile: 20

14 Percentage of poles that are removed by undergrounding: 75%

15 Total annual injuries from collisions with utility poles in CA: 49

16 Annual electrocution rate per 100,000: 0.3

17 Percent of electrocutions due to OH lines: 30%

18 Percent of electrocutions due to UG lines: 1.5%

1 ***Accidents – Workers***

2 *Number of worker-days of construction per mile:*

3

Line Type	Worker-Days
Overhead transmission – poles	35
Overhead transmission – towers	250
Overhead distribution – poles	20
Underground transmission	3,000
Underground distribution	40

4 Annual Fatality Risk (Construction Work): 0.00033

5 Annual Injury Risk (Construction Work): 0.067

6 Annual number of electrocutions due to OH lines (Workers): 11.6

7 Annual number of electrocutions due to UG lines (workers): 1

8 ***TPC:***

9 Varies from scenario to scenario.

10 ***O&M:***

11 Total annual O&M cost per mile for OH lines: \$1,800

12 Total annual O&M cost per mile for UG lines: \$1,500

13 ***Conductor losses:***

14 Varies from scenario to scenario.

15 ***Property Values (Distribution Lines)***

16 Note: For transmission lines, the default values are multiplied by a factor of 2.

17 ***Relative EMF-Impact (Immediate):***

18 Overhead lines – retrofit: 0%

19 Overhead lines – new: 2.5% depreciation

20 Underground lines – retrofit: 2.5% depreciation

21 Underground lines – new: 0%

22 ***Relative Non-EMF Impact (immediate):***

23 Overhead lines – retrofit: 0%

24 Overhead lines – new: 2.5% depreciation

25 Underground lines – retrofit: 2.5% depreciation

26 Underground lines – new: 0%

1 *Relative EMF-Impact (Research Positive; $P = 0.05$):*

2 Overhead lines: 5% depreciation

3 Underground lines: 0%

4 *Relative EMF-Impact (Research Conflicting; $P = 0.725$):*

5 Overhead lines: 0%

6 Underground lines: 0%

7 *Relative EMF-Impact (Research Negative; $P = 0.225$):*

8 Overhead lines: 2.5% appreciation

9 Underground lines: 0%

10 Average property value: \$150,000

11 Number of homes affected by line per mile: 50

12 Year by which research will be known: 14 years from now

13 ***Property Losses:***

14 Total annual property losses due to fires in CA: \$800,000,000

15 Percent of fires due to OH lines: 5%

16 Total annual number of pole collisions in CA: 126

17 Percent of poles that are electrical utility poles: 90%

18 Percentage of poles that are removed by undergrounding: 75%

19 ***Contingencies and Customer Interruptions (Transmission Lines)***

 UG-69 kV=4 minutes/mile/year

20 UG-115 kV=10.4 minutes/mile/year

21 UG-230 kV=12.66 minutes/mile/year

22 OH-69 kV=15.84 minutes/mile/year

23 OH-115 kV=11.10 minutes/mile/year

24 OH-230 kV=9.7 minutes/mile/year

25

26 ***Customer Interruptions (Distribution Lines)***

27 Overhead: SAIDI=81 minutes/customer/year

28 Underground: SAIDI=59 minutes/customer/year

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1 ***Aesthetics***

2 Uses constructed scale that varies from scenario to scenario.

3 ***Trees:***

4 Number of trees per mile: 40

5 Percent reduction of foliage due to OH lines: 20%

6 ***Air pollution:***

7 Percent increase/decrease in household electricity use due to shading: 15%

8 Percent increase/decrease in household electricity use due to conservation: 0%

9 Total annual electricity use in CA: 219GWh

10 Total annual electricity supply in CA: 263GWh

11 Average household electricity use per year: 6,000kWh

12 Percent of fossil fuel capacity in CA: 56%

13 Total annual cost of air pollution due to fossil fuel in CA: \$750,000,000

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Noise and Disruption:
Number of days to build one mile of line:

Line Type	Days per mile
Overhead transmission (pole)	3
Overhead transmission (tower)	6
Overhead distribution	4
Underground transmission	70
Underground distribution	4

Percent of construction days with disruption: 10%

It is important to point out that the majority of the results reported in the next sections of this chapter are based on these default values. Whenever we change default values – either through sensitivity analyses or by parameterizing “points of view” of stakeholders, we will make this clear in the discussion. Ultimately, it is a user decision to define default parameters different from the ones that we choose for our base case analysis.

8.3. Transmission Line Retrofitting – 69 kV

Note: The detailed model specifications of this scenario can be found in the ANALYTICA® Model named “TR-69.ana.”

Basic Layout:

In this scenario, an existing 69 kV transmission line, which connects two substations, A and B, is to be retrofit. The line is single-circuit with an ampacity of 600 A and runs on one side of the road. The distance between the two substations is about 15 miles, divided into four segments, one of which (Segment 3) goes by a school. The basic layout of this scenario is shown in Figure 8.6.



Figure 8.6: Basic Layout of Transmission Line Retrofit (69 kV)

The length of each individual segment as well as the assumed population along with the number of homes per mile are given in Table 8.1.

Table 8.2: Length and Population Characteristics of Route Segments for 69 kV Transmission Line Retrofit

Segment	Length (in miles)	Population (total on both sides)	Number of Adjacent Homes per Mile (both sides)
S1	2	1,000	100
S2	2	2,000	200
S3	0.3	1,000	50
S4	10.7	5,000	100

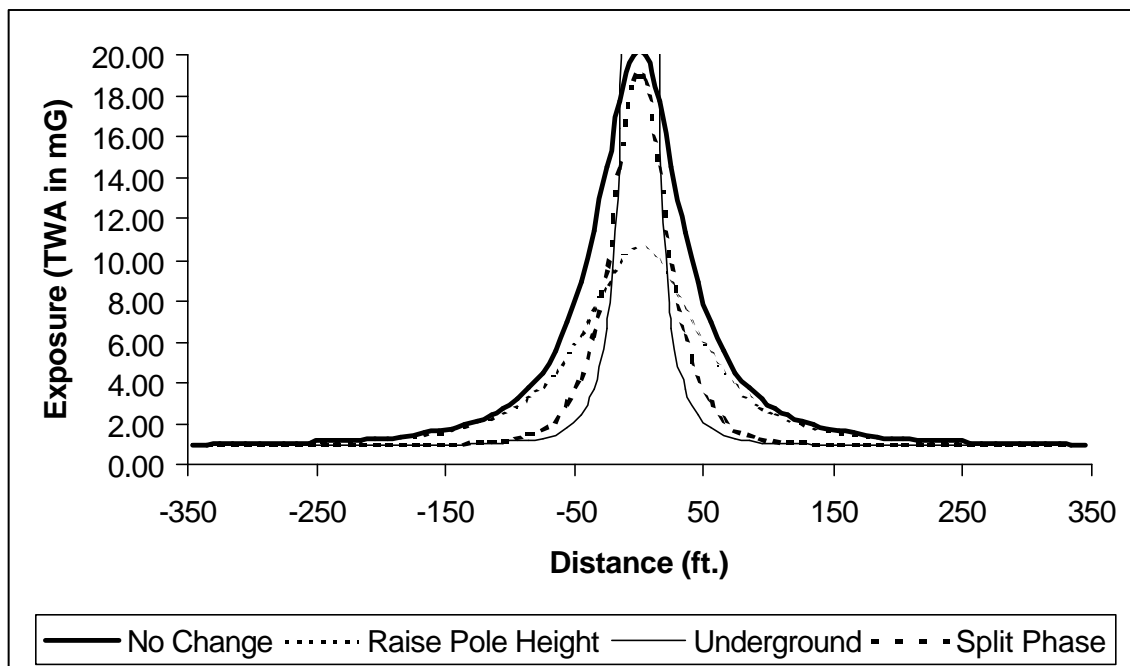
Thus, the overall length of the line is 15 miles. The line affects a total of 9,000 people in about 3,000 homes within 350 feet of the line. 450 of these homes are adjacent to the line and have potential property values impacts.

Four different line configurations are considered as alternatives:

- No Change (existing single-circuit line configuration);
- Raise Pole Height;
- Underground (Solid Dielectric);
- Split-Phase with Reverse Phasing

1 ***Exposure and Exposure Reduction:***

2 Exposures were calculated over a distance of 350' on each side of the line. The
3 exposure profiles for TWA are given in Figure 8.7 for each of the four line
4 configurations.



5 **Figure 8.7: Exposure Profiles (TWA) for 69 kV Transmission Line Retrofit**

6 The exclusion zone in this scenario is set to a total width of 100'. Thus, the
7 exposed population is at least 50' from the line. The corresponding exposure reduction
8 (taking the existing configuration as the standard of comparison) as calculated in the
9 ANALYTICA[®] model is shown in Table 8.3. for each of the potential exposure metrics.
10 Split phasing in combination with reverse phasing achieves the best exposure reductions,
11 exceeding even those of undergrounding. Raising the pole height is not very effective.

1 **Table 8.3: Relative Exposure Reduction for 69 kV Transmission Line Retrofit**

Alternatives	Effects Functions						
	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
No Change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Raise Pole Height	18.25%	24.26%	57.59%	44.29%	14.05%	53.09%	37.99%
Underground	90.01%	98.09%	100%	95.71%	97.02%	99.60%	91.94%
Split Phase	96.35%	99.85%	99%	100%	99.84%	99.90%	97.37%

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3 ***Overall Results***

4 In policy analysis, it is common to first calculate results using a set of base case or
5 default estimates and then to conduct extensive sensitivity analyses. However, since
6 health risks from EMF exposure are highly uncertain, using default risk ratios and
7 probabilities of a hazard might be misleading. Instead, this analysis begins with
8 calculating the consequences on the non-EMF criteria. Then we calculate the equivalent
9 costs of these non-EMF consequences. Based on these equivalent costs, we run a two-
10 way sensitivity analysis on the risk ratio (RR) at 2 mG (or an equivalent midpoint for the
11 other exposure measures) and the degree of certainty that EMF exposure poses a hazard
12 (p). This two-way sensitivity analysis shows which alternative would be preferred, given
13 specific values of RR and p. For illustration, we will also show the results of a complete
14 analysis with specific values of RR and p.

15 The detailed consequences of each of the four alternatives on the non-EMF
16 criteria are shown in Table 8.4. After multiplying the non-monetary consequences by the
17 equivalent costs of their units (see Table 8.1), we obtain the equivalent costs of all
18 consequences as shown in Table 8.5. These results are aggregated in Table 8.6 using the
19 assumption that all equivalent costs are discounted at 3% and that 80% of the total project
20 costs (TPC) are financed over 35 years at a 10% annual interest rate. The results in table
21 8.7 assume a 3% discount rate, but no financing.

1 **Table 8.4: Detailed Non-EMF Consequences for 69 kV Transmission Line Retrofit¹**

Criteria	Alternatives			
	No Change	Raise Pole Height	Underground	Split Phase
Fire Fatalities (Years of Life Lost)	0.82	0.82	0.00	0.82
Fire Injuries (Number)	0.36	0.36	0.00	0.36
Collision Fatalities (Years of Life Lost)	3.18	3.18	0.80	3.18
Collision Injuries (Number)	0.06	0.06	0.02	0.06
Electrocutions - Public (Years of Life Lost)	1.00	1.00	0.18	1.00
Construction Fatalities (Years of Life Lost)	0.00	0.01	3.96	0.01
Construction Injuries (Number)	0.00	0.06	20.10	0.06
Electrocutions - Workers (Years of life Lost)	0.67	0.67	0.21	0.67
Total Project Cost (1998 Dollars)	\$0	\$1,655,000	\$11,640,000	\$2,321,000
Operation and Maintenance Cost (1998 Dollar)	\$945,000	\$945,000	\$787,500	\$945,000
Conductor Losses (1998 Dollars)	\$6,542,000	\$6,542,000	\$8,137,000	\$3,271,000
Property Values (1998 Dollars)	\$0	\$0	-\$12,640,000	\$0
Property Loss - Fires (1998 Dollars)	\$57,850	\$57,850	\$0	\$57,850
Property Loss - Collisions (1998 Dollars)	\$16	\$16	\$4	\$16
Outages - Contingencies (Hours)	138	138	36	138
Outages – (Customer Interruptions Customer-Hours)	275000	275000	71260	275000
Aesthetics (Constructed Scale)	0	0	-30	0
Trees (Equiv.Number of Trees Lost)	0	0	-120	0
Air Pollution (1998 Dollars)	\$0	\$0	-\$98,460	-\$8,038
Noise and Disruption (Person Days)	0	1517	35390	758

2 ¹All estimates are for 35 years. Dollar estimates are in 1998 dollars and not discounted. The estimate for
3 total project cost assumes no financing.

Table 8.5: Detailed Non-EMF Equivalent Costs for 69kV Transmission Line Retrofit¹

Criteria	Alternatives			
	No Change	Raise Pole Height	Underground	Split Phase
Fire Fatalities (Years of Life Lost)	\$81,780	\$81,780	\$0	\$81,780
Fire Injuries (Number)	\$3,616	\$3,616	\$0	\$3,616
Collision Fatalities (Years of Life Lost)	\$318,400	\$318,400	\$79,600	\$318,400
Collision Injuries (Number)	\$638	\$638	\$160	\$638
Electrocutions - Public (Years of Life Lost)	\$99,980	\$99,980	\$18,150	\$99,980
Construction Fatalities (Years of Life Lost)	\$0	\$1,188	\$396,000	\$1,188
Construction Injuries (Number)	\$0	\$603	\$201,000	\$603
Electrocutions - Workers (Years of life Lost)	\$67,110	\$67,110	\$21,000	\$67,110
Total Project Cost (1998 Dollars)	\$0	\$1,655,000	\$11,640,000	\$2,321,000
Operation and Maintenance Cost (1998 Dollar)	\$945,000	\$945,000	\$787,500	\$945,000
Conductor Losses (1998 Dollars)	\$6,542,000	\$6,542,000	\$8,137,000	\$3,271,000
Property Values (1998 Dollars)	\$0	\$0	-\$12,640,000	\$0
Property Loss - Fires (1998 Dollars)	\$57,850	\$57,850	\$0	\$57,850
Property Loss - Collisions (1998 Dollars)	\$16	\$16	\$4	\$16
Outages - Contingencies (Hours)	\$1,375,000	\$1,375,000	\$356,300	\$1,375,000
Outages - (Customer Interruptions Customer-Hours)	\$2,750,000	\$2,750,000	\$712,600	\$2,750,000
Aesthetics (Constructed Scale)	\$0	\$0	-\$300,000	\$0
Trees (Equiv. Number of Trees Lost)	\$0	\$0	-\$120,000	\$0
Air Pollution (1998 Dollars)	\$0	\$0	-\$98,460	-\$8,038
Noise and Disruption (Person Days)	\$0	\$15,170	\$353,900	\$7,583

¹All cost estimates are for 35 years. The costs in this table are not discounted and the total project cost is not financed.

Table 8.6: Equivalent Cost for 69 kV Transmission Line Retrofit
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Cost ¹	Outages	Property Values	Other (Non-EMF)	Total
No Change	\$4,596,000	\$2,533,000	\$0	\$386,400	\$7,515,400
Raise Pole Height	\$7,876,000	\$2,533,000	\$0	\$402,200	\$10,811,200
Underground	\$28,550,000	\$656,300	-\$12,640,000	\$157,300	\$16,723,600
Split Phase	\$7,190,000	\$2,533,000	\$0	\$389,700	\$10,112,700

¹Cost includes total project costs, operations and maintenance cost, and conductor losses.

**Table 8.7: Equivalent Cost for 69 kV Transmission Line Retrofit
(3% Discount Rate, TPC Not Financed)**

Alternatives	Cost ¹	Outages	Property Values	Other (Non-EMF)	Total
No Change	\$4,596,000	\$2,533,000	\$0	\$386,400	\$7,515,400
Raise Pole Height	\$6,251,000	\$2,533,000	\$0	\$402,200	\$9,186,200
Underground	\$17,110,000	\$656,300	-\$12,640,000	\$157,300	\$5,283,600
Split Phase	\$4,910,000	\$2,533,000	\$0	\$389,700	\$7,832,700

¹Cost includes total project costs, operations and maintenance cost, and conductor losses.

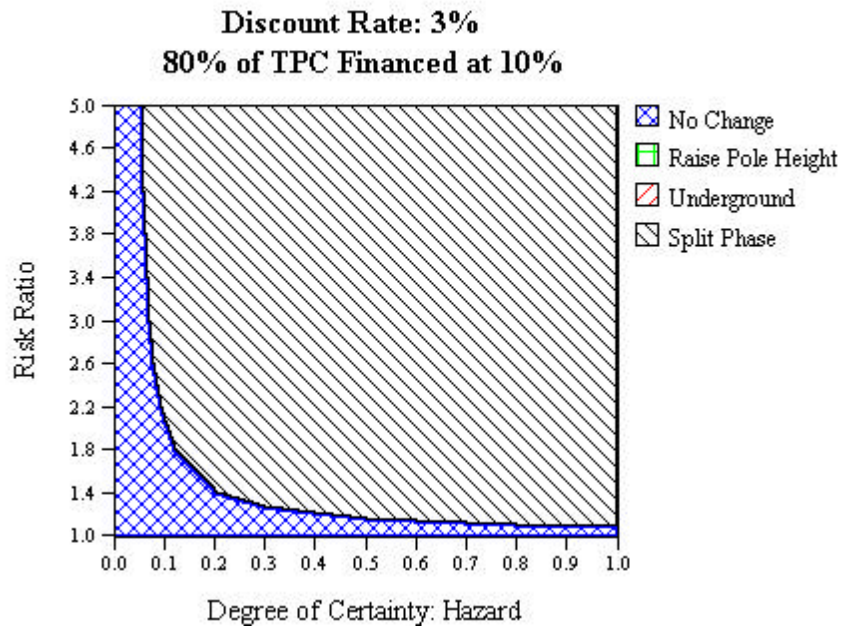
The main observation about Tables 8.6 and 8.7 is that there is a striking difference between the total equivalent costs: When total project costs are financed, undergrounding has by far the highest total cost. However, when total project costs are not financed, it has the lowest cost. Of course, this result is partially due to the large property values benefit that this example assumed for undergrounding. When property values are ignored, undergrounding has the highest costs in both conditions. Note that there is no difference in the financed vs. non-financed case for the direct cost (TPC, O&M, conductor losses of the “No Change” alternative, since this alternative does not involve any TPC, the only cost component that would be financed.

Tables 8.6 and 8.7 ignored the equivalent costs of potential EMF health effects. Yet, some conclusions can be drawn. For example, from Table 8.6 we can conclude that undergrounding would be a reasonable option, if the health risk reductions are worth about \$9.2 million. With the tradeoffs defined in Table 8.1, this would imply that at least two lives needed to be saved over the 35 years of operating the line. Table 8.7 tells a completely different story. When undergrounding is not financed, it is the least cost solution, primarily because of the property values benefit. In other words, no health reductions would be needed to make a case for this alternative.

Sensitivity Analyses

The following sensitivity analyses were performed by varying two parameters of the EMF health risk model: The degree of certainty that exposure to EMFs pose a hazard (p) and the risk ratio (RR) at 2 mG (or an equivalent midpoint for other exposure metrics). All sensitivity analyses were carried out for the TWA exposure measure only. For most sensitivity analyses we considered all diseases: Adult and childhood leukemia, Adult and childhood brain cancer, female breast cancer, and Alzheimer’s disease. For some sensitivity analyses, we only considered leukemia. Other sensitivity analyses, not reported here, show that the results for the 2 mG threshold models are virtually indistinguishable. All sensitivity analyses used a 3% discount rate for the distribution of costs over 35 years. The shaded regions in the graphs show which alternative is preferred (i.e., having the lowest total equivalent cost) for each combination of these two input parameters.

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Figure 8.8: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(All Health Endpoints, TPC Financed, Property Values Included)

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Figure 8.8 shows the results of this two-way sensitivity analysis assuming that 80% of the total project costs are financed at a 10% annual interest rate. For low values of p and RR the lowest cost alternative is not to change the line. For example, if $p=0.1$ and $RR=1.5$, the “No Change” alternative wins. For higher values of p and RR , the alternative to split phase the line (with reverse phasing) is best. For example, if $p=0.3$ and $RR=2$, this would be the case. Undergrounding and raising the pole height are never the best alternative, given the assumptions.

15

Figure 8.9 shows that, when TPC is not financed, undergrounding is the best alternative for most values of p and RR . This is a result of the high property values benefit of undergrounding. Interestingly, when p and RR are very high, the best alternative switches to split phasing. This occurs, because split phasing, combined with reverse phasing, has a slightly better exposure reduction (see Table 8.3). As a result, the relative health benefits of split phasing exceed the property values advantage of undergrounding at higher values of p and RR .

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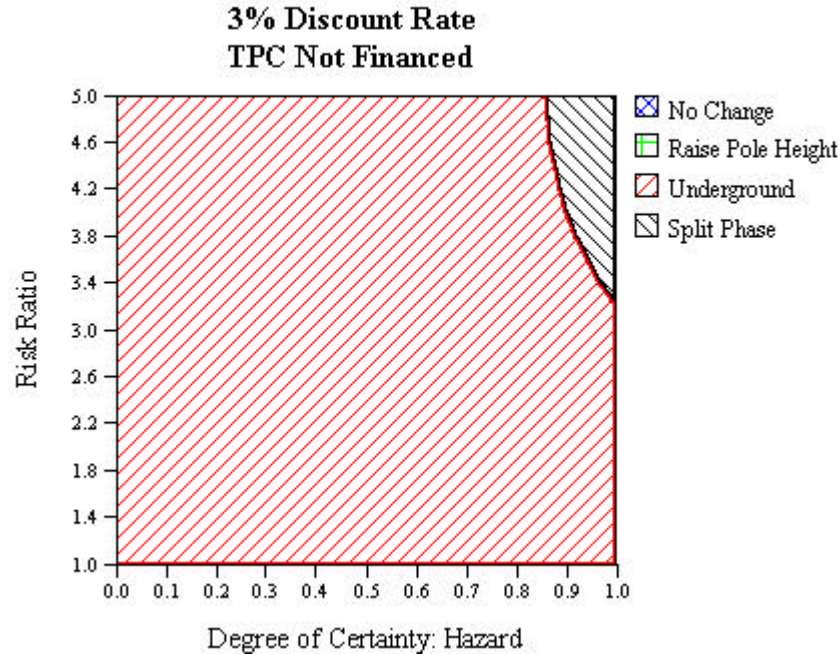
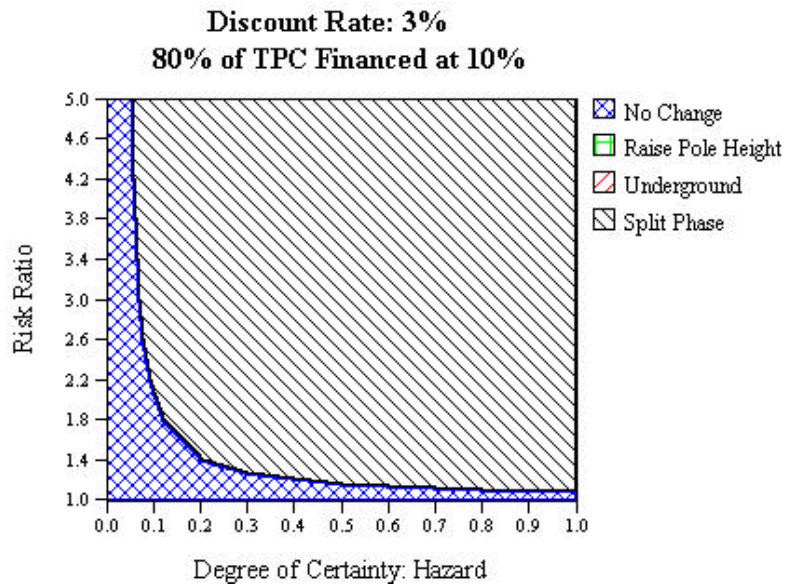


Figure 8.9: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(All Health Endpoints, TPC Not Financed, Property Values Included)

The results of Figures 8.8 and 8.9 are largely determined by the assumptions about financing and by the inclusion of property values benefits. Figures 8.10 and 8.11 show the same results, assuming no property values benefits. In both cases, the preferred alternatives are not to change the line (low values of p and RR) or to split phase it (higher values of p and RR). Undergrounding is never preferred, since it costs substantially more than split phasing and is no longer credited with the property values benefits. Raising the pole height is never preferred, since it costs a fair amount and is not very effective in reducing exposures.

The switch-over from the “No Change” alternative to split phasing occurs for lower values of p and RR for the non-financed case (Figure 8.11) as compared to the financed case (Figure 8.10). This results from the fact that the total project cost of the financed case is higher, thus requiring higher health benefits to justify the expenses.



1

Figure 8.10: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(All Health Endpoints, TPC Financed, Property Values Not Included)

2

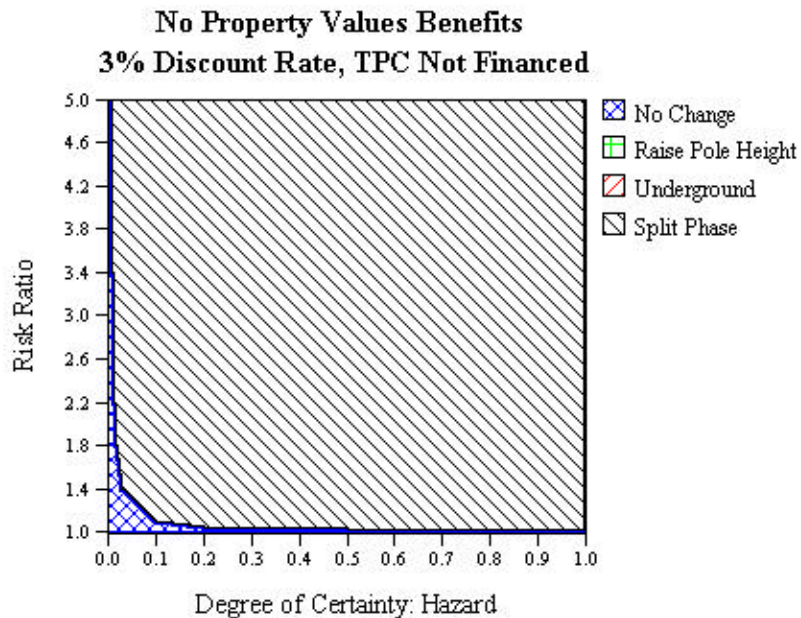


Figure 8.11: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(All Health Endpoints, TPC Not Financed, Property Values Not Included)

3

Up to now, we have assumed that all health endpoints (brain cancer, leukemia, breast cancer, and Alzheimer's disease) are equally implicated in an EMF-health risk association. Of these health endpoints, childhood and adult leukemia have shown the most consistent association with EMF exposure. The next four sensitivity analyses therefore explore the leukemia health endpoint only. This will reduce the total number of potential health effects (to about 20% of the analysis with all health endpoints) and thus makes it less cost-effective to mitigate against EMF exposure. As Figure 8.12 shows, when TPC is financed and leukemia is the only health consideration, the best alternative is not to change the line. This is a result of the relatively low health benefit of reducing exposure by split phasing. When TPC is not financed, the best alternative is to underground the line for all values of p and RR , because of the property values benefit (see Figure 8.13).

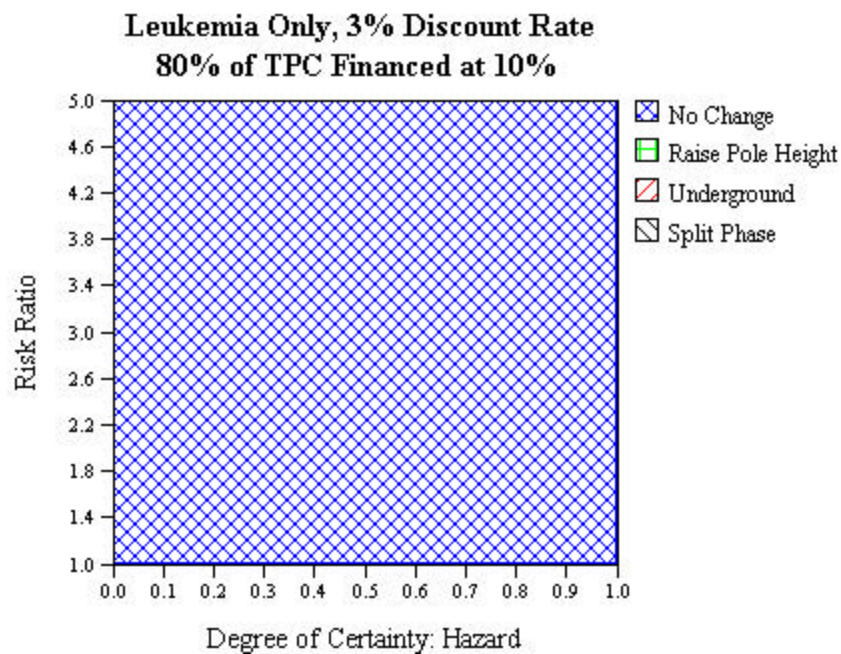


Figure 8.12: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(Leukemia Only, TPC Financed, Property Values Included)

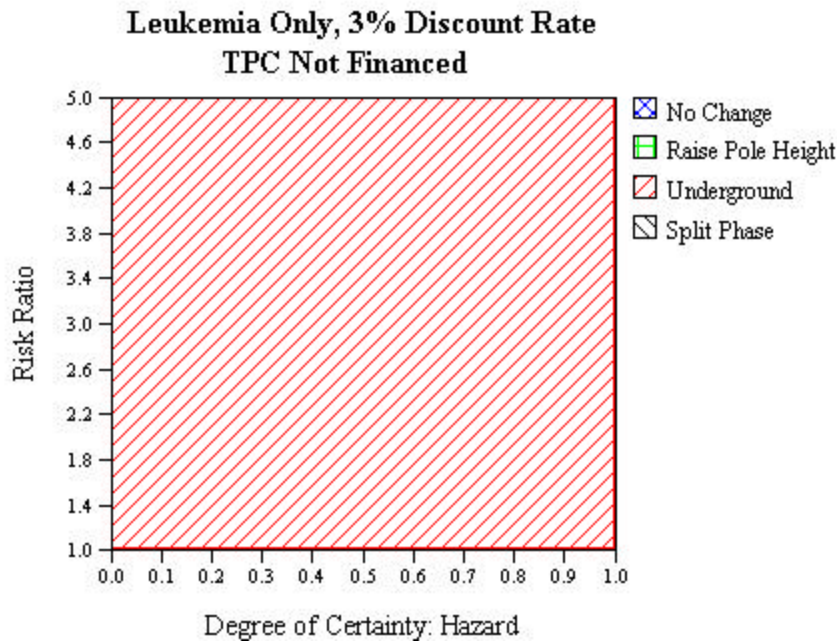


Figure 8.13: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(Leukemia Only, TPC Not Financed, Property Values Included)

Figures 8.14 and 8.15 show the same sensitivity analyses excluding property values benefits. Since property values are affected only by the undergrounding alternative, excluding property values does not change the conclusion that the “No Change” alternative is best for all values of p and R (see Figure 8.14), when TPC is financed. When TPC is not financed and property values are excluded, however, undergrounding is no longer the dominant alternative. Instead we see a pattern in which the “No Change” alternative is preferred for low and medium values of p and RR , while for larger values, split phasing is preferred. Without financing, therefore, split phasing becomes a contender again, even if we only consider leukemia as a health endpoint.

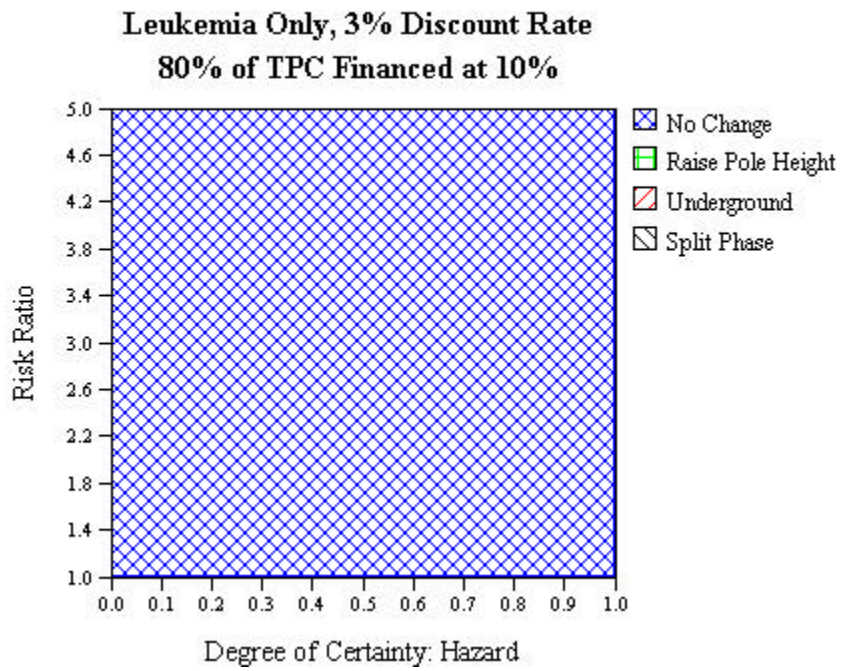


Figure 8.14: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(Leukemia Only, TPC Financed, Property Values Not Included)

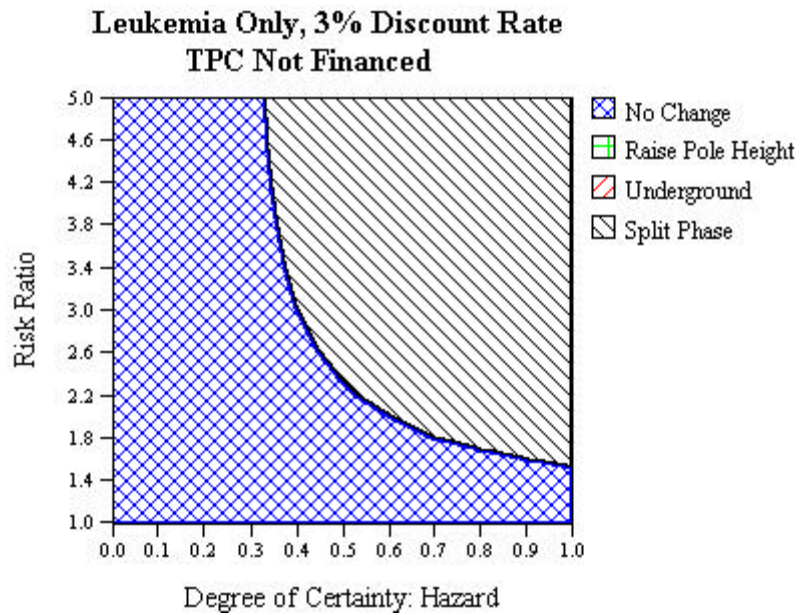
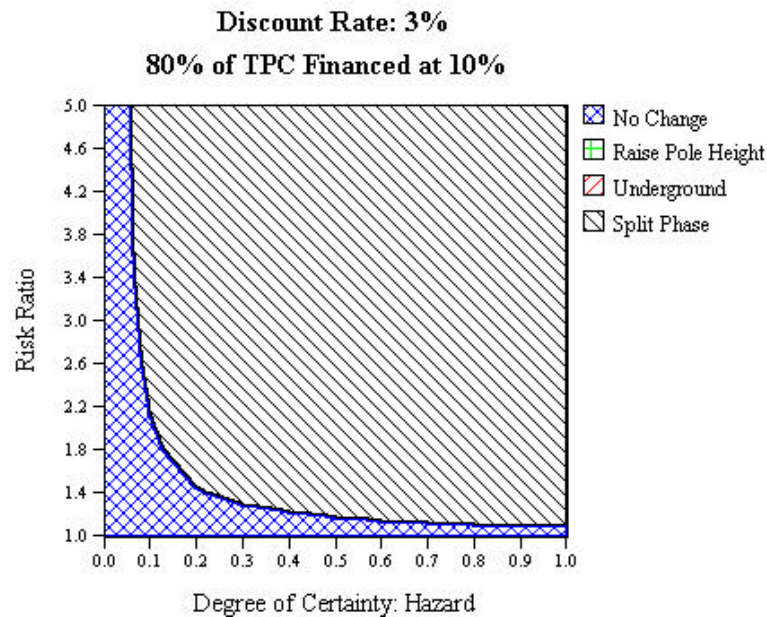


Figure 8.15: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(Leukemia Only, TPC Not Financed, Property Values Not Included)

1

2 The effects of the exposure measure on the switch-over areas are illustrated in
 3 Figures 8.16 and 8.17. There is hardly any difference between using the TWA measure
 4 (Figure 8.8) and the 2 mG linear threshold measure (Figure 8.16). When using the 5 mG
 5 linear threshold measure, the area favoring “No Change” increases somewhat, as would
 6 be expected (Figure 8.17). For the 10 mG linear threshold measure, the best decision not
 7 to change the line for all combinations of RR and p.



8

9

10 **Figure 8.16: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of**
 11 **Certainty for 69kV Transmission Line Retrofit Using a Linear Threshold at 2 mG**
 12 (All Health Endpoints, TPC Not Financed, Property Values Included)

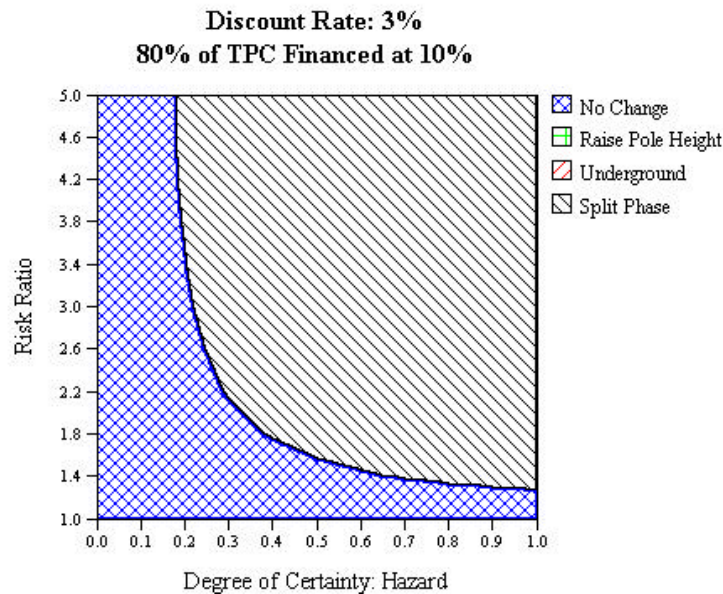


Figure 8.17: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit Using a Linear Threshold at 5 mG
(All Health Endpoints, TPC Not Financed, Property Values Included)

An Illustrative Analysis Including EMF Health Effects

Up to this point, the EMF health part of the model was analyzed only by varying two parameters, the degree of certainty that EMF poses a hazard (p) and the risk ratio (RR) at a medium level of exposure. A policy analyst might want to pick a point in the p -RR space and analyze the implied magnitude of the resulting health effects. Points of interest are those at which the decision switches from not to change the line to taking some mitigation measure. For illustration, we choose the $p=0.1$ and $RR=2$ in the following analysis. This results in the estimates of health consequences as shown in Table 8.8. It should be noted that these are estimates for 35 years of exposure and that these are expected consequences, assuming a probability of 0.10 – in other words the consequences would be ten times as high, if we knew that EMF posed a health hazard.

Table 8.8: Illustrative Calculation of Health Consequences for $p=0.10$ and $RR=2$ for All Health Endpoints¹

Criteria	Alternatives			
	No Change	Raise Pole		
		Height	Underground	Split Phase
Adult Brain Cancer - Fatal (Years of Life Lost)	6.79	5.53	0.68	0.25
Adult Brain Cancer - Non-Fatal (Number)	0.42	0.34	0.04	0.02
Adult Leukemia - Fatal (Years of Life Lost)	8.87	7.23	0.89	0.32
Adult Leukemia - Non-Fatal (Number)	0.73	0.59	0.07	0.03
Breast Cancer - Fatal (Years of Life Lost)	20.91	17.04	2.09	0.76
Breast Cancer - Non-Fatal (Number)	4.36	3.55	0.43	0.16
Alzheimer's Disease (Number)	4.52	3.69	0.45	0.17
Adult Other - Fatal (Years of Life Lost)	0.00	0.00	0.00	0.00
Adult Other - Non-Fatal (Number)	0.00	0.00	0.00	0.00
Childhood Brain Cancer - Fatal (Years of Life Lost)	1.66	1.36	0.17	0.06
Childhood Brain Cancer - Non-Fatal (Number)	0.08	0.06	0.01	0.00
Childhood Leukemia - Fatal (Years of Life Lost)	2.61	2.13	0.26	0.10
Childhood Leukemia - Non-Fatal (Number)	0.13	0.11	0.01	0.00
Childhood Other - Fatal (Years of Life Lost)	0.00	0.00	0.00	0.00
Childhood Other - Non-Fatal (Number)	0.00	0.00	0.00	0.00
Worker Brain Cancer - Fatal (Years of Life Lost)	0.00	0.00	0.00	0.00
Worker Brain Cancer - Non-Fatal (Number)	0.00	0.00	0.00	0.00
Worker Leukemia - Fatal (Years of Life Lost)	0.00	0.00	0.00	0.00
Worker Leukemia - Non-Fatal (Number)	0.00	0.00	0.00	0.00

¹ All estimates are for a 35 year life of the line

Table 8.9 shows the corresponding equivalent costs of these health consequences, using the tradeoffs defined in Table 8.1. Table 8.10 shows the summary of the equivalent expected costs of the major criteria, including health effects, when financing TPC and using a discount rate of 3%. Figure 8.18 shows the results of Table 8.10 as a stacked bar chart. Table 8.11 and Figure 8.19 show the same results with the assumption that TPC is not financed.

1 **Table 8.9: Illustrative Calculation of the Equivalent Costs of Health Consequences**
2 **for p=0.10 and RR=2 for All Health Endpoints¹**

Criteria	Alternatives			
	No Change	Raise Pole Height	Underground	Split Phase
Adult Brain Cancer - Fatal (Years of Life Lost)	\$679,100	\$553,400	\$67,820	\$24,800
Adult Brain Cancer - Non-Fatal (Number)	\$126,800	\$103,300	\$12,660	\$4,631
Adult Leukemia - Fatal (Years of Life Lost)	\$887,200	\$722,900	\$88,590	\$32,400
Adult Leukemia - Non-Fatal (Number)	\$217,600	\$177,300	\$21,730	\$7,946
Breast Cancer - Fatal (Years of Life Lost)	\$2,091,000	\$1,704,000	\$208,800	\$76,370
Breast Cancer - Non-Fatal (Number)	\$1,306,000	\$1,065,000	\$130,500	\$47,720
Alzheimer's Disease (Number)	\$904,500	\$737,000	\$90,320	\$33,030
Adult Other - Fatal (Years of Life Lost)	\$0	\$0	\$0	\$0
Adult Other - Non-Fatal (Number)	\$0	\$0	\$0	\$0
Childhood Brain Cancer - Fatal (Years of Life Lost)	\$166,300	\$135,500	\$16,600	\$6,073
Childhood Brain Cancer - Non-Fatal (Number)	\$39,420	\$32,120	\$3,937	\$1,440
Childhood Leukemia - Fatal (Years of Life Lost)	\$261,400	\$213,000	\$26,110	\$9,548
Childhood Leukemia - Non-Fatal (Number)	\$67,010	\$54,600	\$6,692	\$2,447
Childhood Other - Fatal (Years of Life Lost)	\$0	\$0	\$0	\$0
Childhood Other - Non-Fatal (Number)	\$0	\$0	\$0	\$0
Worker Brain Cancer - Fatal (Years of Life Lost)	\$1	\$1	\$3	\$1
Worker Brain Cancer - Non-Fatal (Number)	\$0	\$0	\$0	\$0
Worker Leukemia - Fata (Years of Life Lost)	\$2	\$2	\$5	\$2
Worker Leukemia - Non-Fatal (Number)	\$0	\$0	\$0	\$0
Total Equivalent Costs of Health Effects	\$6,746,334	\$5,498,124	\$673,767	\$246,409

3
4 ¹ All cost estimates are for 35 years and they are undiscounted.

5
6 **Table 8.10: Equivalent Cost for 69 kV Transmission Line Retrofit**
7 **(3% Discount Rate, 80% of TPC Financed at 10% Interest)**

Alternatives	Health-EMF Cost		Outages	Property Values	Other	Total
No Change	\$4,142,000	\$4,596,000	\$2,533,000	\$0	\$386,400	\$11,657,400
Raise Pole Height	\$3,375,000	\$7,876,000	\$2,533,000	\$0	\$402,200	\$14,186,200
Underground	\$413,600	\$28,550,000	\$656,300	-\$12,640,000	\$157,300	\$17,137,200
Split Phase	\$151,300	\$7,190,000	\$2,533,000	\$0	\$389,700	\$10,264,000

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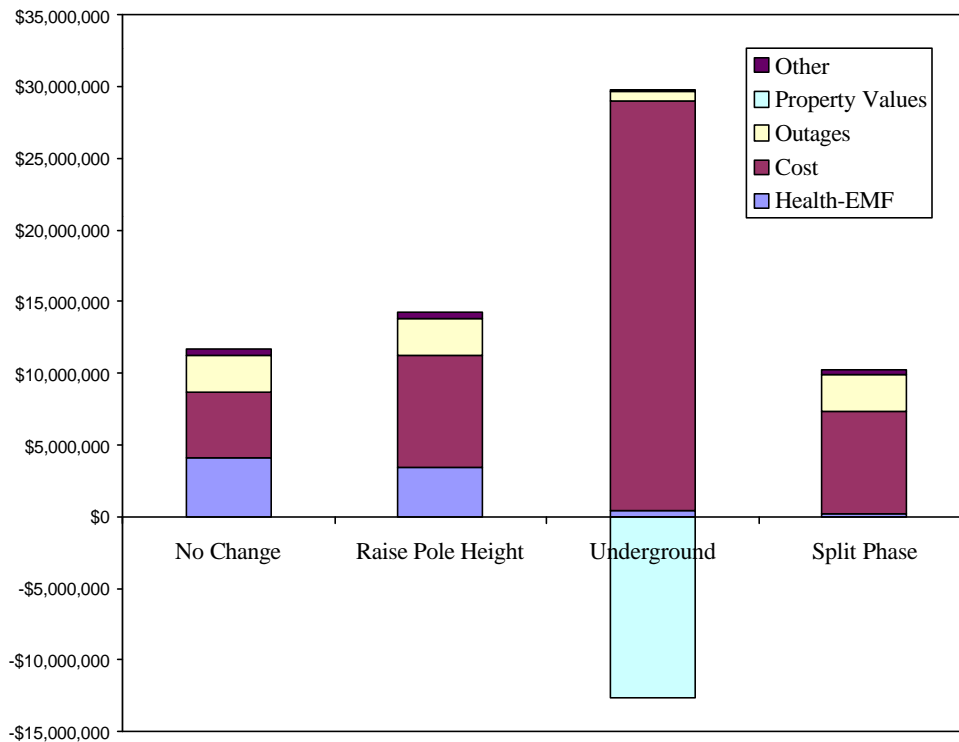


Figure 8.18: Stacked Bar Chart of Equivalent Cost Components for the 69kV Transmission Line Retrofit (3% Discount Rate, TPC Financed)

Table 8.10: Equivalent Cost for 69 kV Transmission Line Retrofit (3% Discount Rate, TPC Not Financed)

Alternatives	Health-EMF	Cost	Outages	Property Values	Other	Total
No Change	\$4,142,000	\$4,596,000	\$2,533,000	\$0	\$386,400	\$11,657,400
Raise Pole Height	\$3,375,000	\$6,251,000	\$2,533,000	\$0	\$402,200	\$12,561,200
Underground	\$413,600	\$17,110,000	\$656,300	-\$12,640,000	\$157,300	\$5,697,200
Split Phase	\$151,300	\$4,910,000	\$2,533,000	\$0	\$389,700	\$7,984,000

These tables and figures illustrate that the assumptions about financing and property values make a major difference to the overall result. With financing split phasing is preferred to undergrounding, even if property value benefits are assumed. This occurs, because undergrounding has a high total project cost, and financing this cost makes it prohibitively expensive. Without financing, undergrounding becomes the preferred alternative, if property value benefits are considered, otherwise split phasing wins.

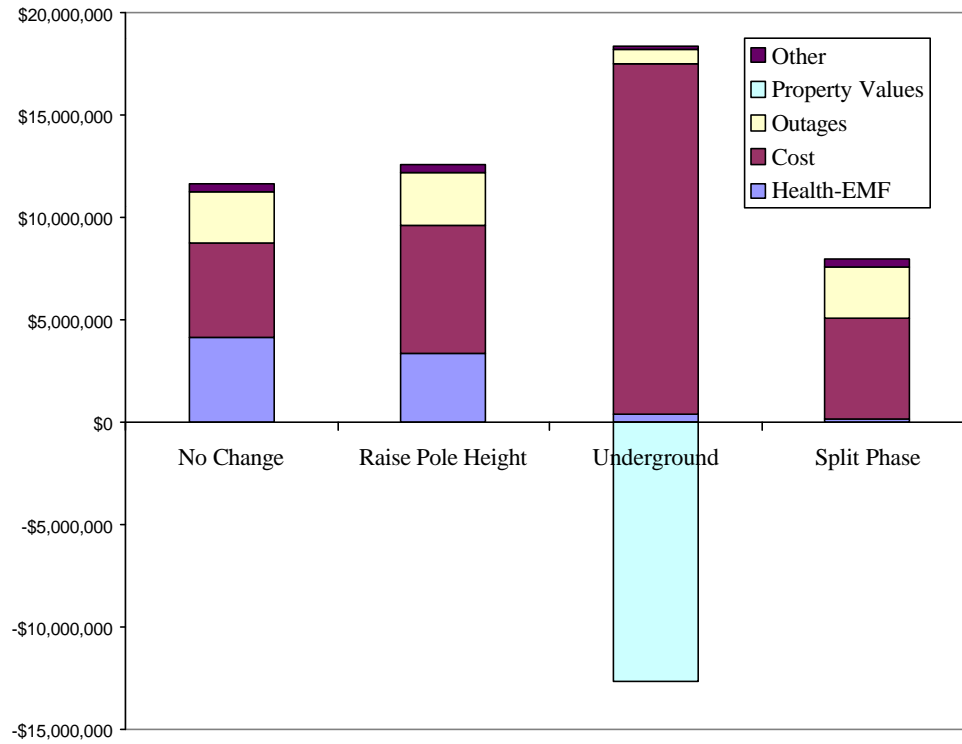


Figure 8.19: Stacked Bar Chart of Equivalent Cost Components for the 69kV Transmission Line Retrofit (3% Discount Rate, TPC Not Financed)

8.4. Transmission Line Retrofitting – 115 kV

Note: The detailed model specifications of this scenario can be found in the ANALYTICA® Model named “TR-115.ana.”

Basic Layout:

In this scenario, an existing 115 kV transmission line which connects two substations, A and B, is to be retrofit. The line is double-circuit with an ampacity of 600 A and runs on one side of the road. The distance between the two substations is about 15 miles, divided into four segments, one of which (Segment 3) goes by a school. The basic layout of this scenario is shown in Figure 8.20.



Figure 8.20: Basic Layout of Transmission Line Retrofit (115 kV)

The length of each individual segment as well as the assumed population along with the number of homes per mile are given in Table 8.12.

Table 8.12: Length and Population Characteristics of Route Segments for 115 kV Transmission Line Retrofit

Segment	Length (in miles)	Population (total on both sides)	Number of Adjacent Homes per Mile (both sides)
S1	2	1,000	100
S2	2	2,000	200
S3	0.3	1,000	50
S4	10.7	5,000	100

Thus, the overall length of the line is 15 miles. The line affects a total of 9,000 people in 3,000 homes within 350 feet. 450 homes are adjacent to the line and have potential property values impacts.

Three different line configurations are considered:

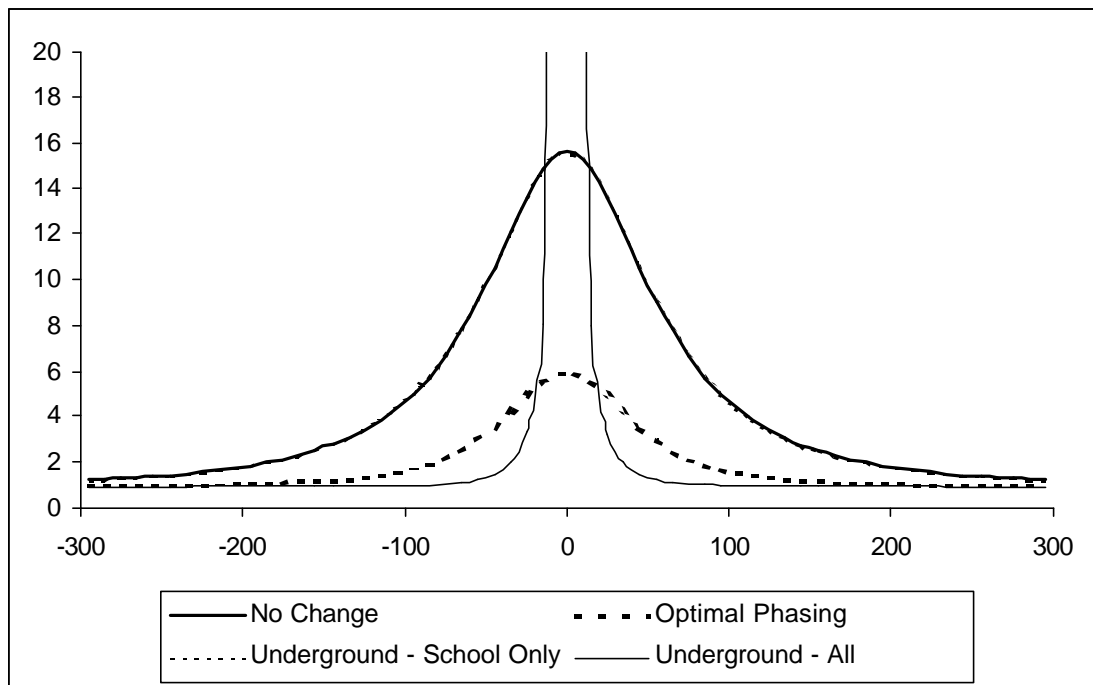
- Base Case (existing double-circuit line configuration);
- Optimal Phasing
- Underground (Solid Dielectric)

1 In addition, the model differentiates whether or not the possible mitigation is
2 performed on all segments of the line or only on individual segments. In particular, the
3 model assumes that undergrounding might be done in sensitive areas only, for example
4 along the school (in Segment 3). Therefore the model distinguishes between the
5 following four alternatives:

- 6 • No Change (leave base case configurations on all segments)
- 7 • Optimal Phasing (all segments)
- 8 • Underground – School Only (leave base case configuration for the other
9 segments)
- 10 • Underground – All (underground all segments)
- 11

12 ***Exposure and Exposure Reduction:***

14 Exposures were calculated over a distance of 350' on each side of the line. The
15 exposure profiles for TWA are given in Figure 8.21 for each of the four line
16 configurations. The profile for undergrounding the school only is virtually
17 indistinguishable from the profile of not changing the line.



18 **Figure 8.21: Exposure Profiles (TWA) for 115 kV Transmission Line Retrofit**

The exclusion zone in this scenario is set to a total width of 100'. Thus, the exposed population is at least 50' from the line. The corresponding exposure reduction (taking the existing configuration as the standard of comparison) as calculated in the ANALYTICA[®] model is shown in Table 8.13 for each of the potential exposure metrics.

Table 8.13: Relative Exposure Reduction for 115 kV Transmission Line Retrofit

Effects Function (Exposure Measure)							
Alternatives	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
No Change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Optimal Phasing	81.83%	87.60%	96.53%	98.30%	80.84%	96.24%	98.13%
Underground - School	1.96%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%
Underground - All	98.13%	99.92%	99.77%	100.00%	99.81%	99.96%	99.93%

Overall Result

The equivalent costs of the major non-EMF criteria are shown in Tables 8.14 and 8.15. Table 8.14 shows the discounted and financed case, Table 8.15 shows the discounted, unfinanced case. As in the 69kV scenario, the results are strikingly different. In the financed case, undergrounding is the most expensive alternative. In the non-financed case it is the least expensive one.

**Table 8.14: Equivalent Cost for 115 kV Transmission Line Retrofit
(3% Discount Rate, 80% of TPC Financed at 10% Interest)**

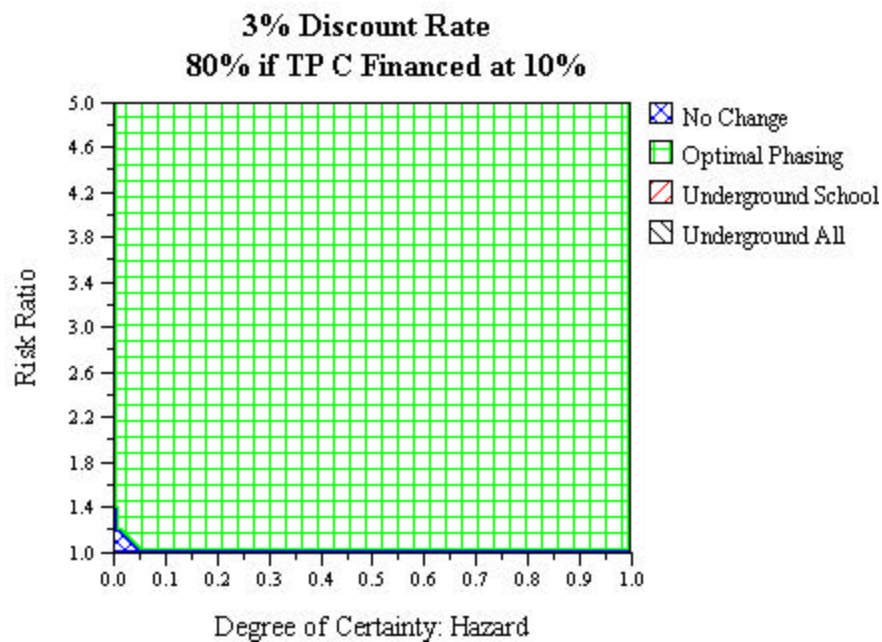
Alternatives	Cost	Outages	Property Values	Other	Total
No Change	\$8,612,000	\$1,795,000	\$0	\$381,700	\$10,788,700
Optimal Phasing	\$8,664,000	\$1,795,000	\$0	\$389,900	\$10,848,900
Underground - School Only	\$10,120,000	\$1,793,000	-\$225,000	\$370,900	\$12,283,900
Underground - All	\$56,610,000	\$1,673,000	-\$25,280,000	\$1,740	\$33,004,740

**Table 8.15: Equivalent Cost for 115 kV Transmission Line Retrofit
(3% Discount Rate, TPC not Financed)**

Alternatives	Cost	Outages	Property Values	Other	Total
No Change	\$8,612,000	\$1,795,000	\$0	\$381,700	\$10,788,700
Optimal Phasing	\$8,638,000	\$1,795,000	\$0	\$389,900	\$10,822,900
Underground - School Only	\$9,361,000	\$1,793,000	-\$225,000	\$370,900	\$11,299,900
Underground - All	\$32,290,000	\$1,673,000	-\$25,280,000	\$1,740	\$8,684,740

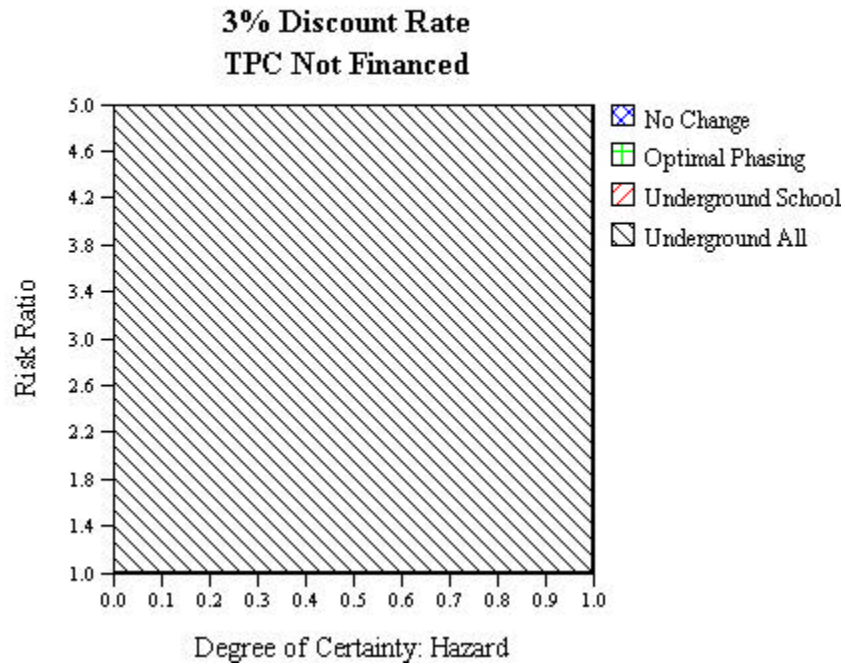
Sensitivity Analyses

Figure 8.22 shows the result of the two-way sensitivity analysis on p and RR assuming that 80% of the total project costs are financed at a 10% annual interest rate. The “No Change” alternative has the lowest cost only for very small values of p and RR. For most values of p and RR, the alternative to optimally phase the line is best. Undergrounding near the school or undergrounding the whole line are never the best alternative, given the assumptions.



**Figure 8.22: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of
Certainty for 115kV Transmission Retrofit using TWA
(All Health Endpoints, TPC Financed, Property Values Included)**

1 Figure 8.23 shows the same sensitivity analysis assuming that TPC is not
2 financed. In this case, undergrounding is the preferred option for all values of p and RR,
3 because of the property values benefits.



4
5 **Figure 8.23: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of**
6 **Certainty for 115kV Transmission Retrofit using TWA**
7 (All Health Endpoints. TPC Not Financed, Property Values Included)
8

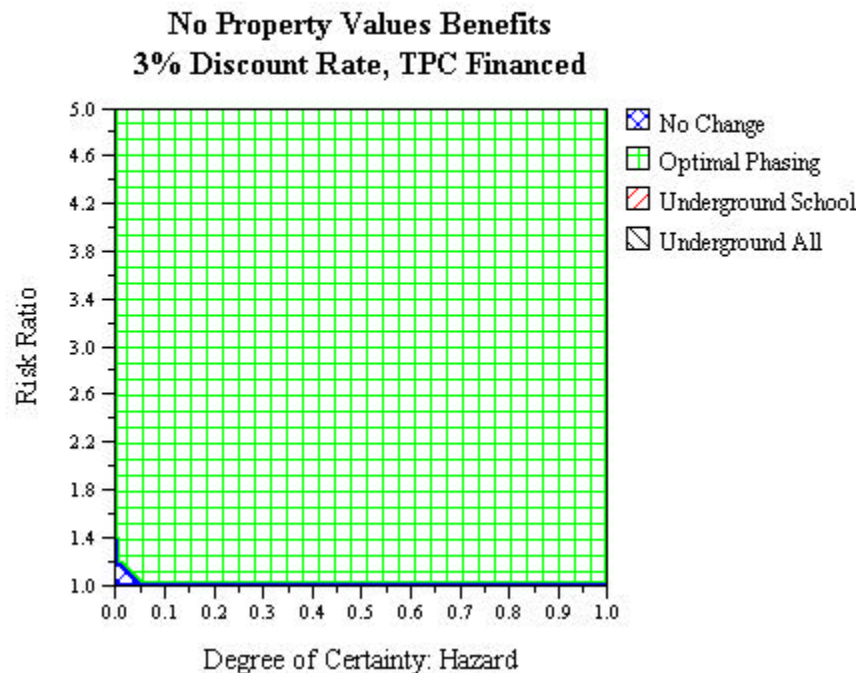


Figure 8.24: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 115kV Transmission Retrofit using TWA
(All Health Endpoints, TPC Financed, Property Values Not Included)

Figure 8.24 shows the same sensitivity analyses assuming that there are no property values benefits and TPC is financed. The “No Change” alternative is preferred only for very low values of p and RR . Undergrounding is never preferred. When TPC is not financed and property values are not considered, the results are the same as in Figure 8.22.

An analysis with leukemia health endpoints shows a similar pattern as figures 8.20-8.22: Optimal phasing is preferred for most values of p and RR and for most assumptions. Undergrounding the whole line is preferred, when TPC is not financed and when counting property value benefits. Undergrounding the stretch of line near the school is never a preferred option.

An Illustrative Analysis Including EMF Health Effects

To illustrate specific results including EMF health effects, we chose $p=0.10$ and $RR=2$. Table 8.16 shows the equivalent costs of the major criteria including EMF health assuming that TPC is financed. Figure 8.25 shows the same information as a stacked bar chart. Table 8.17 and Figure 8.26 are the corresponding results assuming that TPC is not

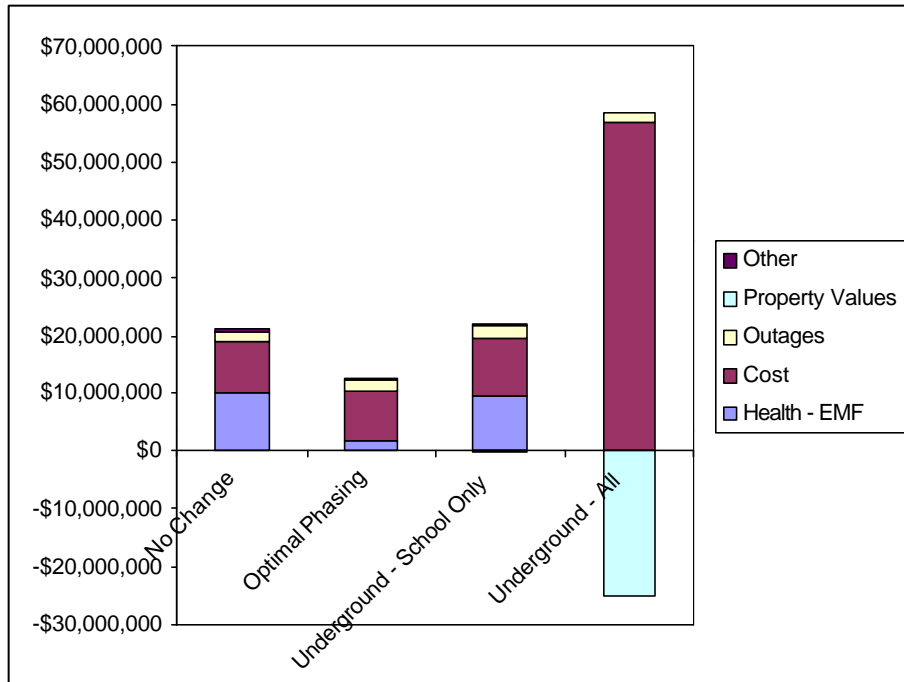
financed. The results tell the same story as the sensitivity analyses: Financing and property values make the difference when choosing between undergrounding and optimal phasing as mitigation alternatives. With financing total project costs, optimal phasing is best. Without financing and when property value benefits are taken into account, undergrounding is best.

Table 8.16: Equivalent Cost for 115kV Transmission Line Retrofit
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
No Change	\$10,270,000	\$8,612,000	\$1,795,000	\$0	\$381,700	\$21,060,000
Optimal Phasing	\$1,872,000	\$8,664,000	\$1,795,000	\$0	\$389,900	\$12,720,000
Underground - School Only	\$9,524,000	\$10,120,000	\$1,793,000	-\$225,000	\$370,900	\$21,580,000
Underground - All	\$192,500	\$56,610,000	\$1,673,000	-\$25,280,000	\$1,740	\$33,200,000

Table 8.17: Equivalent Cost for 115kV Transmission Line Retrofit
(3% Discount Rate, TPC Not Financed)

Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
No Change	\$10,270,000	\$8,612,000	\$1,795,000	\$0	\$381,700	\$21,060,000
Optimal Phasing	\$1,872,000	\$8,638,000	\$1,795,000	\$0	\$389,900	\$12,700,000
Underground - School Only	\$9,524,000	\$9,361,000	\$1,793,000	-\$225,000	\$370,900	\$20,820,000
Underground - All	\$192,500	\$32,290,000	\$1,673,000	-\$25,280,000	\$1,740	\$8,879,000



**Figure 8.25: Stacked Bar Chart of Equivalent Cost Components
for 115kV Transmission Line Retrofit**
(3% Discount Rate, 80% of TPC Financed at 10%)

1

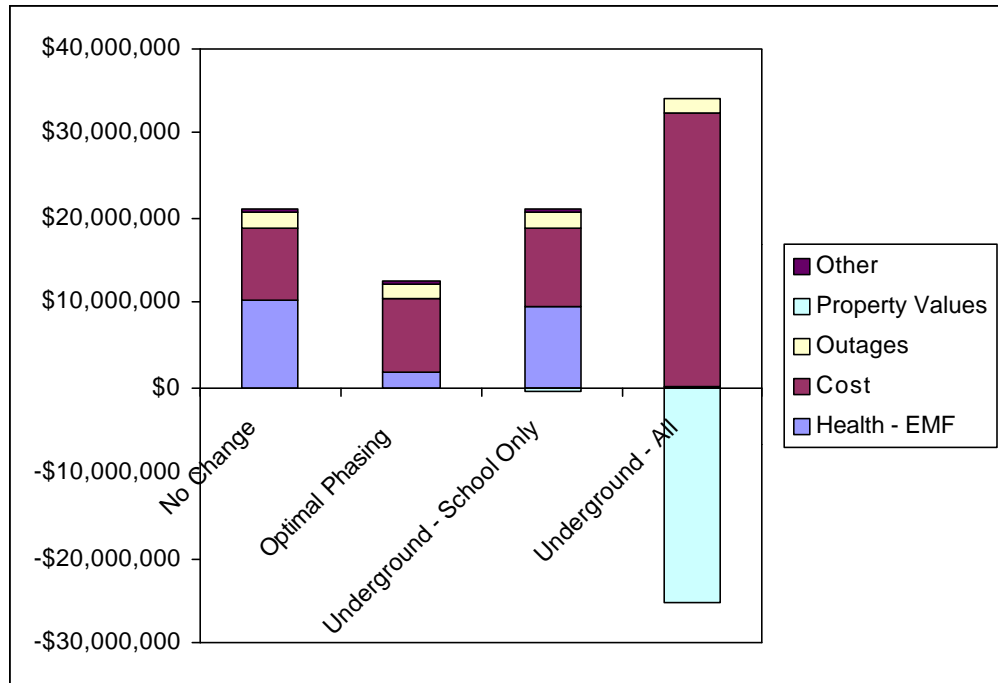


Figure 8.26: Stacked Bar Chart of Equivalent Cost Components for 115kV Transmission Line Retrofit
(3% Discount Rate, TPC Not Financed)

8.5 Transmission Line Retrofitting – 230kV

Note: The detailed model specifications of this scenario can be found in the ANALYTICA® Model named “TR-230.ana.”

Basic Layout

In this scenario, an existing 230 kV bulk power transport line connects a generation plant in a rural location with a substation in a suburban area. The line is double-circuit with an ampacity of 1,000 A and is centered in a 120’ ROW. The typical current is assumed to be 500 A. The overall length of the line is divided into five segments with different land use and population characteristics.

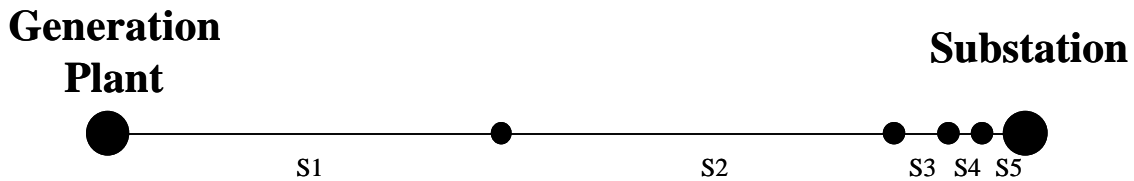


Figure 8.27: Basic Layout of Transmission Line Retrofit (230 kV)

The length of each individual segment as well as the assumed population along with the number of homes per mile and land use characteristics are given in Table 8.18.

Table 8.18: Length and Population Characteristics of Route Segments for 230 kV Transmission Line Retrofit

Segment	Length (in miles)	Land Use	Population (total on both sides)	Number of Adjacent Homes per Mile (both sides)
S1	20	Rural	100	10
S2	20	State Forest	0	0
S3	7	Mixed	1,000	20
S4	1	Commercial/Business	1,000	0
S5	2	Dense Suburban	2,000	100

Thus, the line affects a total of 4,100 people and about 1,400 homes within 350 ft. of the line. 130 of these homes are adjacent to the line and may have property values effects.

1 Five different line configurations are considered as alternatives:

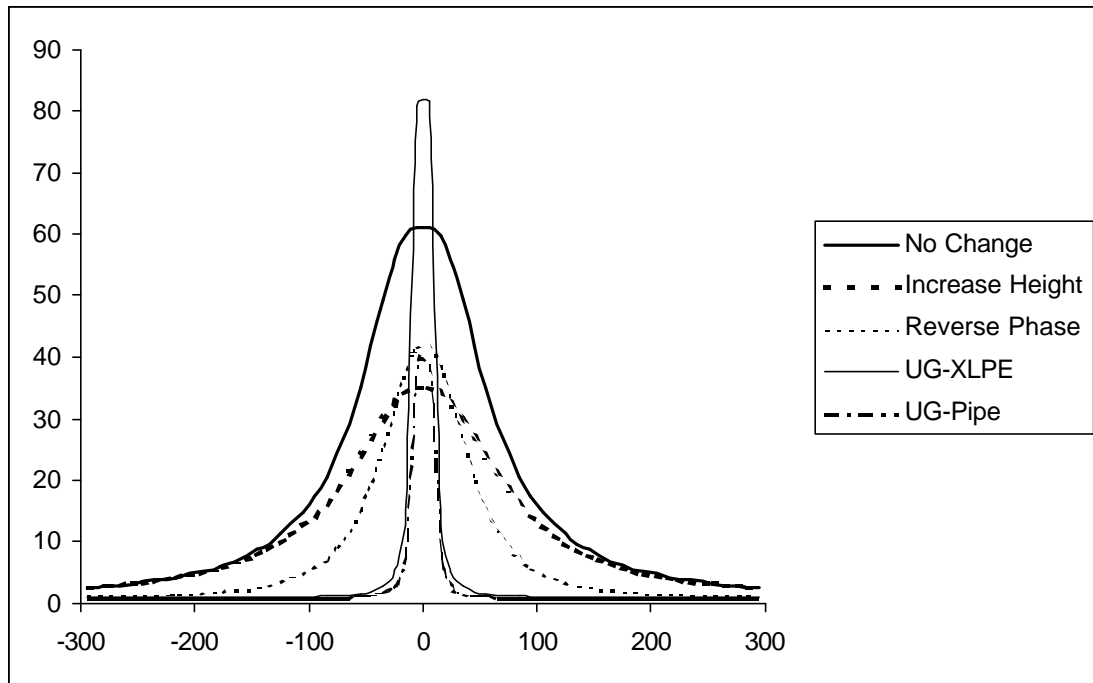
2

- 3
- No Change (existing double-circuit line configuration);
 - 4 • Increase Height;
 - 5 • Reverse Phase;
 - 6 • Underground-XLPE (Solid Dielectric);
 - 7 • Underground-Pipe (High Pressure Oil Filled Cables – HPOF).

8

9 ***Exposure and Exposure Reduction:***

10 Exposures were calculated over a distance of 350' on each side of the line. The
11 exposure profiles for TWA are given in Figure 8.28 for each of the five line
12 configurations.



13 **Figure 8.28: Exposure Profiles (TWA) for 230 kV Transmission Line Retrofit**

14 The exclusion zone in this scenario is set to a total width of 120'. Thus, the
15 exposed population is at least 60' from the line. The corresponding exposure reduction
16 (taking the existing configuration as the standard of comparison) as calculated in the
17 ANALYTICA® model is shown in Table 8.24 for each of the potential exposure
18 measures.

1

2 **Table 8.19: Relative Exposure Reduction for 230 kV Transmission Line Retrofit**

Effects Function (Exposure Measure)							
Alternatives	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
No Change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Increase Height	16.96%	15.95%	19.43%	27.48%	0.78%	5.20%	14.76%
Reverse Phase	72.58%	74.00%	78.99%	85.79%	57.85%	70.07%	81.58%
JG-XLPE	99.28%	99.93%	100.00%	100.00%	99.68%	99.98%	99.99%
JG-Pipe	99.81%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

3

4 **Overall Results**

5 The equivalent costs of the major non-EMF criteria are shown in Tables 8.20 and
6 8.21. Table 8.20 shows the discounted and financed case, Table 8.21 shows the
7 discounted, unfinanced case. The results are different from the 69kV and 115kV
8 retrofitting scenarios, in that undergrounding is much more expensive than the other
9 options, even when giving it credit for property values benefits. The relatively low
10 property value appreciation is a result of the fact that this line runs through large
11 segments of areas with low population density. The implication of the large costs of
12 undergrounding is that the health effects reduction would have to be large before
13 undergrounding would be cost-effective. Roughly, the equivalent value of life savings
14 would have to be between \$200 million to \$ 300 million, or approximately 40 to 60 lives
15 to justify undergrounding this line.

16 **Table 8.20: Equivalent Cost for 230 kV Transmission Line Retrofit**

(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Cost ¹	Outages	Property Values	Other	Total
No Change	\$50,790,000	\$4,603,000	\$0	\$1,272,000	\$56,665,000
Increase Height	\$65,950,000	\$4,603,000	\$0	\$1,281,000	\$71,834,000
Reverse Phase	\$50,850,000	\$4,603,000	\$0	\$1,273,000	\$56,726,000
UG-XLPE	\$346,800,000	\$8,824,000	-\$7,100,000	-\$922,000	\$347,602,000
UG-Pipe	\$397,600,000	\$8,824,000	-\$7,100,000	-\$917,300	\$398,406,700

18
19 ¹Cost Includes Total Project Cost, Operation and Maintenance Cost, and Conductor Losses.

20

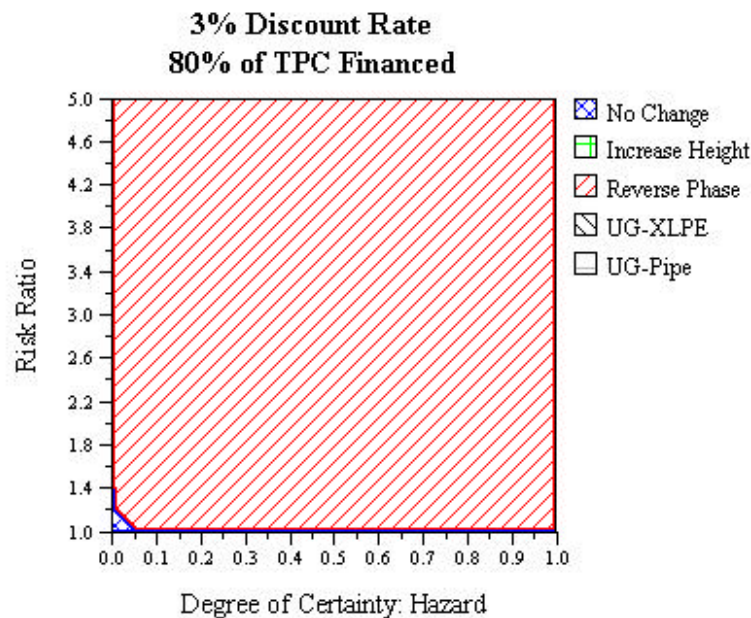
**Table 8.21: Equivalent Cost for 230 kV Transmission Line Retrofit
(3% Discount Rate, TPC not Financed)**

Alternatives	Cost ¹	Outages	Property Values	Other	Total
No Change	\$50,790,000	\$4,603,000	\$0	\$1,272,000	\$56,665,000
Increase Height	\$58,430,000	\$4,603,000	\$0	\$1,281,000	\$64,314,000
Reverse Phase	\$50,820,000	\$4,603,000	\$0	\$1,273,000	\$56,696,000
UG-XLPE	\$189,000,000	\$8,824,000	-\$7,100,000	-\$922,000	\$189,802,000
UG-Pipe	\$218,100,000	\$8,824,000	-\$7,100,000	-\$917,300	\$218,906,700

¹Cost Includes Total Project Cost, Operation and Maintenance Cost, and Conductor Losses

Sensitivity Analyses

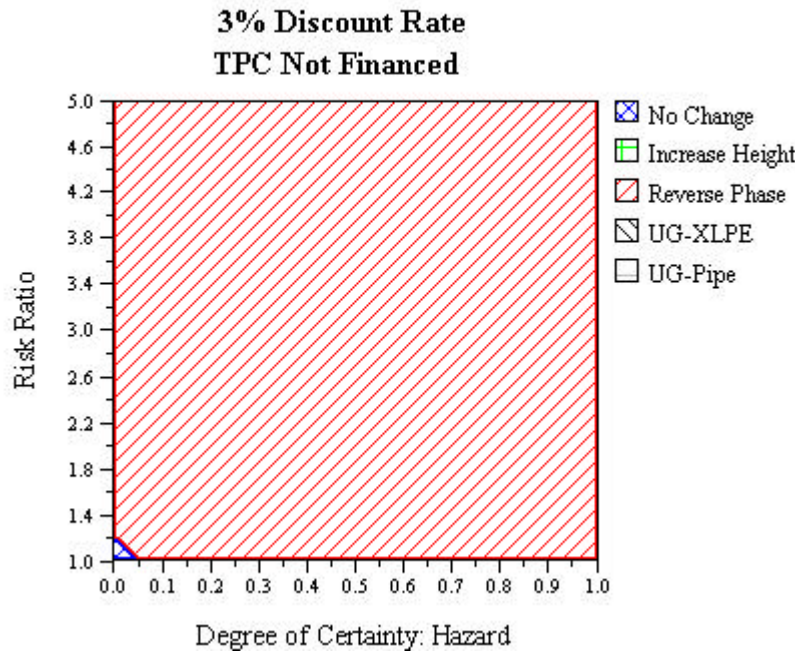
Figure 8.29 shows the result of the two-way sensitivity analysis on p and RR assuming that 80% of the total project costs are financed at a 10% annual interest rate. Not changing the line is best only for very low values of p and RR. For most values of p and RR, the alternative to reverse phase the line is best. The undergrounding alternatives and increasing the tower height are never best, given the assumptions.



**Figure 8.29: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 230kV Transmission Retrofit using TWA
(All Health Endpoints, TPC Financed, Property Values Included)**

1

2 Figure 8.30 shows the same sensitivity analysis assuming that TPC is not
3 financed. The results are very similar. Reverse Phasing is best for most values of p and
4 RR, the undergrounding alternatives or increasing the tower height are never best.



5

6

7 **Figure 8.30: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of**
8 **Certainty for 230kV Transmission Retrofit using TWA (TPC Not Financed)**

9

10 Removing the property values benefits from the analysis does not change the
11 results, since this only penalizes the undergrounding alternatives. An analysis with
12 leukemia health endpoints shows a similar pattern as figures 8.27 and 8.28: Reverse
13 phasing is preferred for all but very small values of p and RR.

An Illustrative Analysis Including EMF Health Effects

For illustration of specific results including EMF health effects, we chose $p=0.10$ and $RR=2$. Table 8.22 shows the equivalent costs of the major criteria including EMF health assuming that TPC is financed. Figure 8.31 shows the same information as a stacked bar chart. Table 8.23 and Figure 8.32 are the corresponding results assuming that TPC is not financed. The results tell the same story as the sensitivity analyses: Reverse phasing is best, independent of the assumptions about financing or property values.

Table 8.22: Equivalent Cost for 230kV Transmission Line Retrofit
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

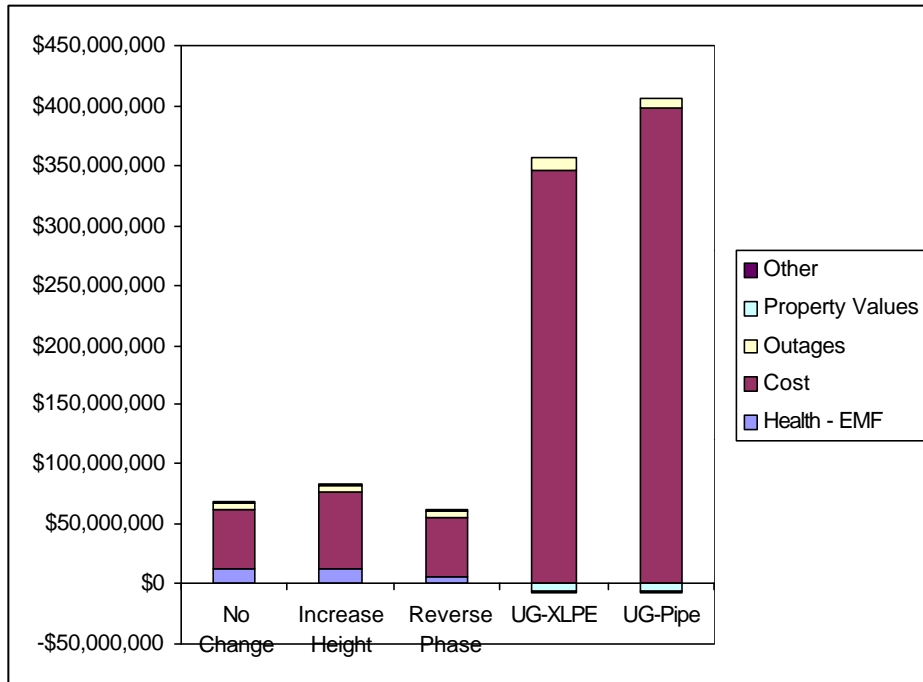
Alternatives	Health - EMF	Cost ¹	Outages	Property Values	Other	Total
No Change	\$11,710,000	\$50,790,000	\$4,603,000	\$0	\$1,272,000	\$68,380,000
Increase Height	\$11,270,000	\$65,950,000	\$4,603,000	\$0	\$1,281,000	\$83,110,000
Reverse Phase	\$4,718,000	\$50,850,000	\$4,603,000	\$0	\$1,273,000	\$61,440,000
UG-XLPE	\$132,100	\$346,800,000	\$8,824,000	-\$7,100,000	-\$922,000	\$347,800,000
UG-Pipe	\$34,090	\$397,600,000	\$8,824,000	-\$7,100,000	-\$917,300	\$398,400,000

¹Cost Includes Total Project Cost, Operation and Maintenance Cost, and Conductor Losses

Table 8.23: Equivalent Cost for 230kV Transmission Line Retrofit
(3% Discount Rate, TPC Not Financed)

Alternatives	Health - EMF	Cost ¹	Outages	Property Values	Other	Total
No Change	\$11,710,000	\$50,790,000	\$4,603,000	\$0	\$1,272,000	\$68,380,000
Increase Height	\$11,270,000	\$58,430,000	\$4,603,000	\$0	\$1,281,000	\$75,590,000
Reverse Phase	\$4,718,000	\$50,820,000	\$4,603,000	\$0	\$1,273,000	\$61,410,000
UG-XLPE	\$132,100	\$189,000,000	\$8,824,000	-\$7,100,000	-\$922,000	\$189,900,000
UG-Pipe	\$34,090	\$218,100,000	\$8,824,000	-\$7,100,000	-\$917,300	\$218,900,000

¹Cost Includes Total Project Cost, Operation and Maintenance Cost, and Conductor Losses



**Figure 8.31: Stacked Bar Chart of Equivalent Cost Components
for 230kV Transmission Line Retrofit**
(3% Discount Rate, 80% of TPC Financed at 10%)

1

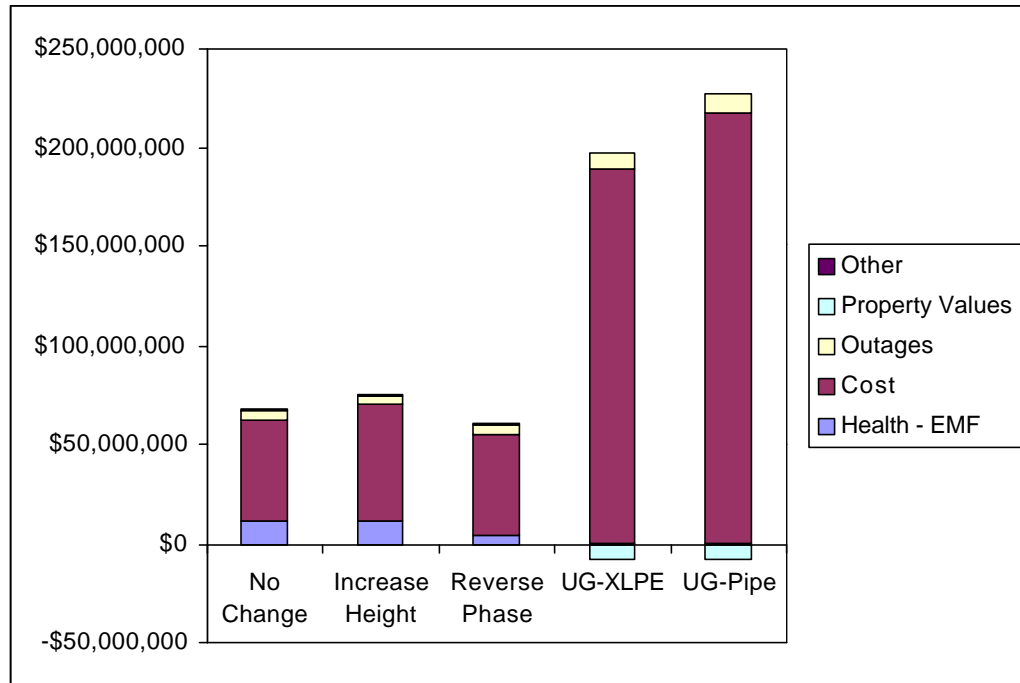


Figure 8.32: Stacked Bar Chart of Equivalent Cost Components for 115kV Transmission Line Retrofit
(3% Discount Rate, TPC Not Financed)

8.6 New Transmission Lines – Scenario A

Note: The detailed model specifications of this scenario can be found in the ANALYTICA® Model named “TN-115-A.ana.”

Basic Layout:

In this scenario, a new 115 kV transmission line with a maximum ampacity of 1000 A is built to connect two points, A and B. The shortest distance from A to B passes through relatively densely populated areas and goes directly by a school. Therefore two alternate routes are considered: one that will merely bypass the school and another route that will avoid the school as the densely populated areas at the expense of a much longer distance. The basic layout of the three routes and their individual segments is shown in Figure 8.33.

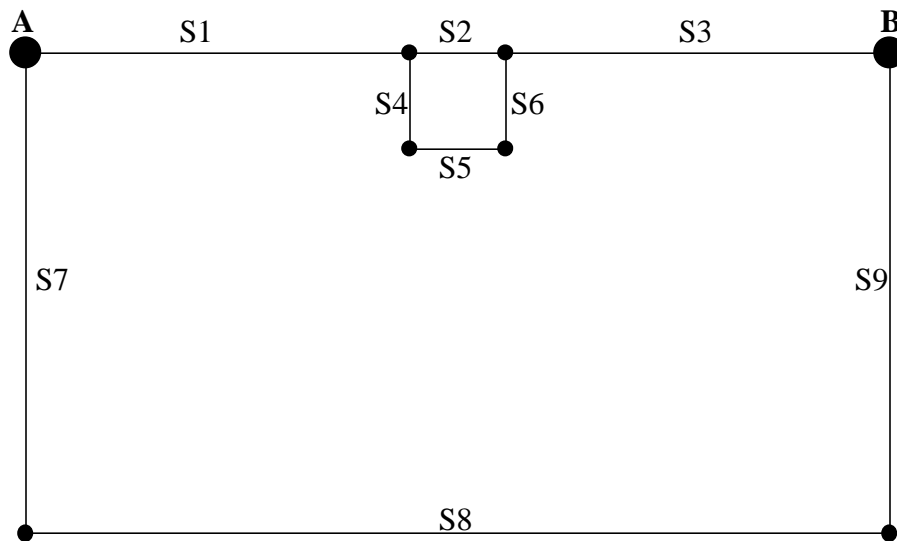


Figure 8.33: Routes and route segments for 115 kV New Transmission Line Scenario A

The three different routes and their individual segments are:

- Route A: S1 - S2 - S3
- Route B: S1 - S4 - S5 - S6 - S3
- Route C: S7 - S8 - S9

Note that segment S2 and therefore Route A goes by a school.

The length of each individual segment and the assumed population for each segment are given in Table 8.24.

Table 8.24: Length and Population Characteristics of Route Segments for 115 kV New Transmission Line Scenario A

Segment	Length (in miles)	Population (total on both sides)	Number of Adjacent Homes per Mile (both sides)
S1	5	2,400	20
S2	0.5	500	0
S3	5	1,200	10
S4	1	240	20
S5	0.5	120	40
S6	1	240	40
S7	5	600	10
S8	10.5	1,200	20
S9	5	600	10

Thus, route A is 10.5 miles long and affects a total population of 4,100 people, including about 350 children in the school at Segment A. Route B is 12.5 miles long and affects a total of 4,200 people. Finally, Route C is 20.5 miles long and affects a total of 2,400 people. The last column shows for each segment the number of homes per mile that are directly adjacent to the powerline.

Three different line configurations are considered:

- Triangular Post Configuration (Conductor 1272 AAC; Narcissus);
- Split-Phase with Horizontal Post Construction (Conductor 795 AAC; Arbutus; a smaller conductor is used since with this configuration two conductors will carry the load of one phase, so the ampacity of each is 500 A).
- Underground (Solid Dielectric).

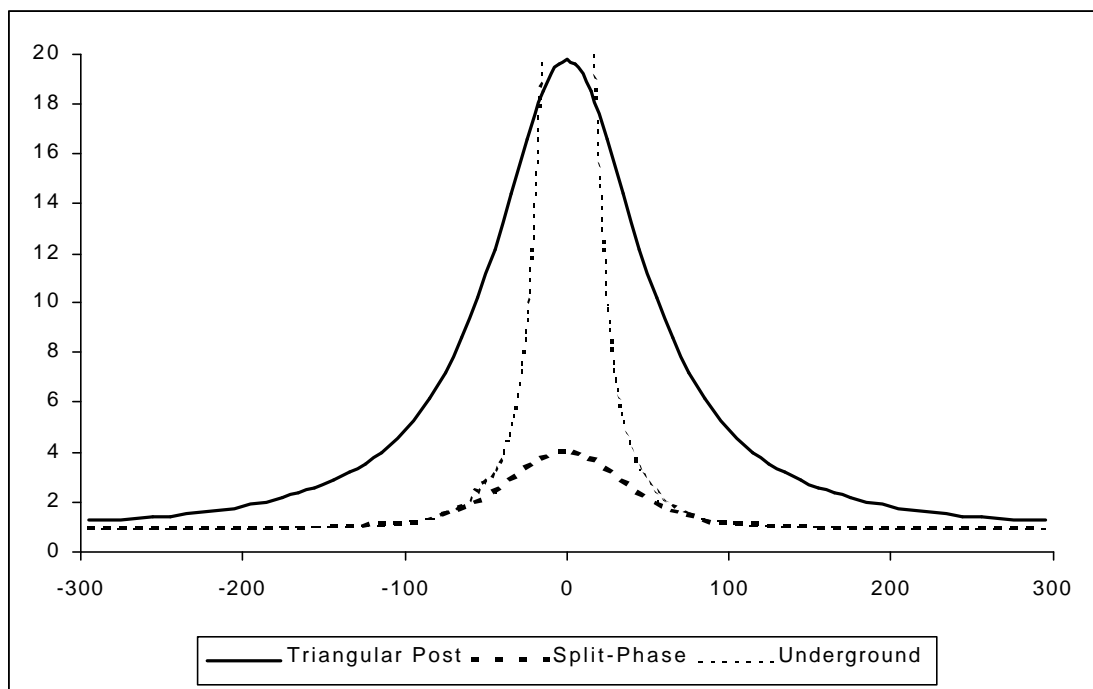
Combining these three line configurations with the three routes gives the following nine alternatives:

- Triangular Post - Route A
- Split-Phase Route A
- Underground - Route A
- Triangular Post - Route B
- Split-Phase Route B
- Underground - Route B

- Triangular Post - Route C
- Split-Phase Route C
- Underground - Route C

5 ***Exposure and Exposure Reduction:***

6 Exposures were calculated over a distance of 300' on each side of the line. The
 7 exposure profiles for TWA are given in Figure 8.34 for each of the four line
 8 configurations.



9 **Figure 8.34: Exposure Profiles for Different Line Configurations**
 10 **for 115 kV New Transmission Line Scenario A (Metric: TWA)**

11 The exclusion zone in this scenario is set to a total width of 100'. Thus, the
 12 exposed population is at least 50' from the line. The corresponding exposure reduction
 13 (taking the Triangular Post configuration as the standard of comparison) as calculated in
 14 the ANALYTICA[®] model is shown in Table 8.25.

Table 8.25: Relative Exposure Reduction for 115 kV New Transmission Line Scenario A

Alternatives	Effects Function						
	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
Triangular Post	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Split Phase	93.83%	97.61%	100.00%	99.71%	95.06%	99.77%	99.65%
Underground	91.84%	96.03%	100.00%	99.71%	92.34%	99.68%	99.53%

Overall Results

The equivalent costs of the major non-EMF criteria are shown in Tables 8.26 and 8.27. Table 8.26 shows the discounted and financed case, Table 8.27 shows the results for the discounted and unfinanced case. The main observation about these tables are that the direct costs dominate the results and that route selection and undergrounding cause the main differences between the equivalent costs of the alternatives.

Table 8.26: Equivalent Cost for the 115kV New Transmission Line Scenario A
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Cost	Outages	Property Values	Other	Total
Triangular Post - Route A	\$95,110,000	\$1,256,000	\$2,250,000	\$502,700	\$99,118,700
Split-Phase - Route A	\$94,800,000	\$1,256,000	\$2,250,000	\$554,900	\$98,860,900
Underground - Route A	\$114,200,000	\$1,171,000	\$0	\$267,100	\$115,638,100
Triangular Post - Route B	\$113,200,000	\$1,496,000	\$3,450,000	\$614,300	\$118,760,300
Split-Phase - Route B	\$112,900,000	\$1,496,000	\$3,450,000	\$676,300	\$118,522,300
Underground - Route B	\$135,900,000	\$1,394,000	\$0	\$341,900	\$137,635,900
Triangular Post - Route C	\$185,700,000	\$2,453,000	\$4,650,000	\$989,100	\$193,792,100
Split-Phase - Route C	\$185,100,000	\$2,453,000	\$4,650,000	\$1,090,000	\$193,293,000
Underground - Route C	\$219,200,000	\$2,286,000	\$0	\$530,800	\$222,016,800

Table 8.27: Equivalent Cost for the 115kV New Transmission Line Scenario A
(3% Discount Rate, TPC not Financed)

Alternatives	Cost	Outages	Property Values	Other	Total
Triangular Post - Route A	\$50,720,000	\$1,256,000	\$2,250,000	\$502,700	\$54,728,700
Split-Phase - Route A	\$49,950,000	\$1,256,000	\$2,250,000	\$554,900	\$54,010,900
Underground - Route A	\$59,510,000	\$1,171,000	\$0	\$267,100	\$60,948,100
Triangular Post - Route B	\$60,380,000	\$1,496,000	\$3,450,000	\$614,300	\$65,940,300
Split-Phase - Route B	\$59,460,000	\$1,496,000	\$3,450,000	\$676,300	\$65,082,300
Underground - Route B	\$70,820,000	\$1,394,000	\$0	\$341,900	\$72,555,900
Triangular Post - Route C	\$99,030,000	\$2,453,000	\$4,650,000	\$989,100	\$107,122,100
Split-Phase - Route C	\$97,510,000	\$2,453,000	\$4,650,000	\$1,090,000	\$105,703,000
Underground - Route C	\$114,300,000	\$2,286,000	\$0	\$530,800	\$117,116,800

Sensitivity Analyses

Figure 8.35 shows the results of the two-way sensitivity analysis on p and RR assuming that 80% of the total project costs are financed at a 10% annual interest rate. The result is very simple: for all values of p and RR, the best alternative is to use route A and to split phase the line. This occurs, because Route A is the shortest and least expensive route and because split phasing reduces both line losses and potential EMF risks.

All other sensitivity analyses produced the same stable result: Route A and split phasing is always preferred over all other alternatives, independent of whether or not the TPC is financed, whether or not property values are being considered, and whether one considers all health effects or only leukemia.

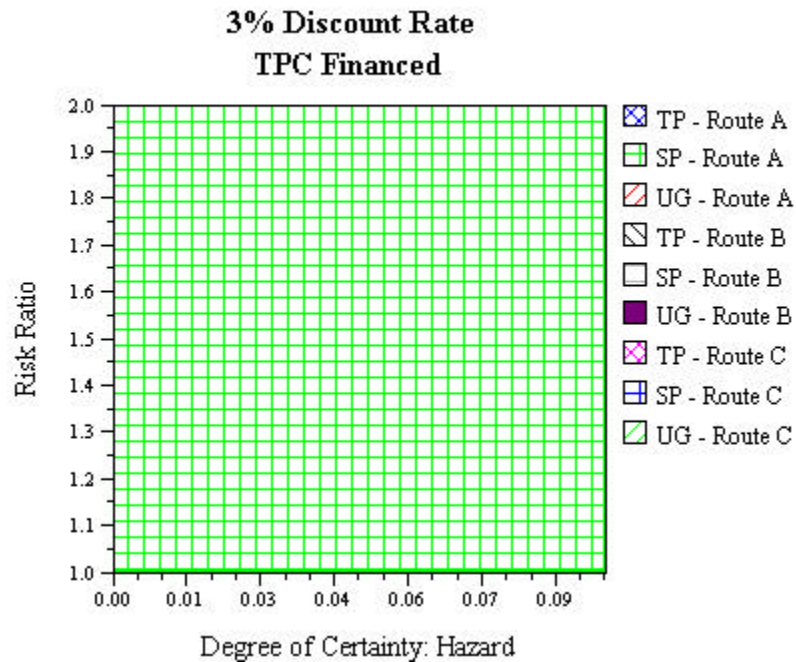


Figure 8.35: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the 115 New Transmission Line Scenario
(All Health Endpoints, TPC Financed, Property Values Included)

An Illustrative Analysis Including EMF Health Effects

For illustration of specific results including EMF health effects, we chose $p=0.10$ and $RR=2$. Table 8.28 shows the equivalent costs of the major criteria including EMF health assuming that TPC is financed. Figure 8.36 shows the same information as a stacked bar chart. Table 8.29 and Figure 8.37 are the corresponding results assuming that TPC is not financed. Both tables and both graphs tell the same story: Direct cost (TPC, O&M and line losses) dominates the results. The longer the route, the more costly the line is. Split phasing is the best mitigation alternative for all routes, because it substantially reduces health risks and has a lower direct cost, due to less line losses.

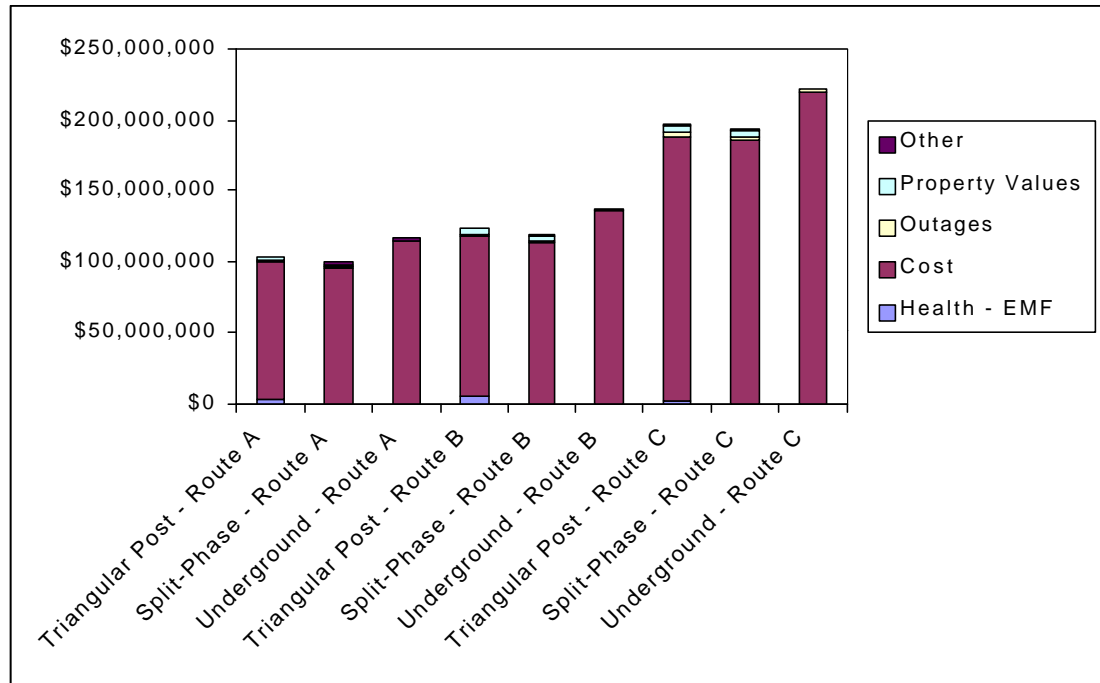
Table 8.28: Equivalent Cost for the New 115 kV Transmission Line Scenario A
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
Triangular Post - Route A	\$4,648,000	\$95,110,000	\$1,256,000	\$2,250,000	\$502,700	\$103,800,000
Split-Phase - Route A	\$293,300	\$94,800,000	\$1,256,000	\$2,250,000	\$554,900	\$99,150,000
Underground - Route A	\$387,800	\$114,200,000	\$1,171,000	\$0	\$267,100	\$116,100,000
Triangular Post - Route B	\$5,219,000	\$113,200,000	\$1,496,000	\$3,450,000	\$614,300	\$124,000,000
Split-Phase - Route B	\$329,300	\$112,900,000	\$1,496,000	\$3,450,000	\$676,300	\$118,800,000
Underground - Route B	\$435,400	\$135,900,000	\$1,394,000	\$0	\$341,900	\$138,100,000
Triangular Post - Route C	\$2,982,000	\$185,700,000	\$2,453,000	\$4,650,000	\$989,100	\$196,800,000
Split-Phase - Route C	\$188,200	\$185,100,000	\$2,453,000	\$4,650,000	\$1,090,000	\$193,500,000
Underground - Route C	\$248,800	\$219,200,000	\$2,286,000	\$0	\$530,800	\$222,300,000

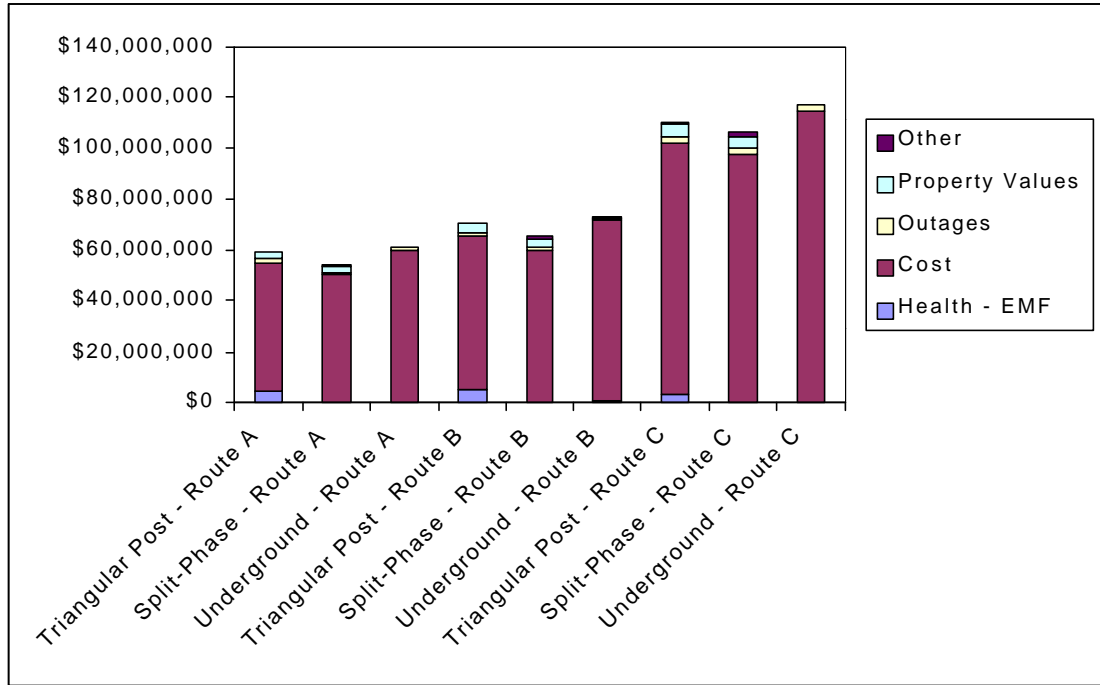
Table 8.29: Equivalent Cost for the New 115 kV Transmission Line Scenario A
(3% Discount Rate, TPC Not Financed)

Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
Triangular Post - Route A	\$4,648,000	\$50,720,000	\$1,256,000	\$2,250,000	\$502,700	\$59,380,000
Split-Phase - Route A	\$293,300	\$49,950,000	\$1,256,000	\$2,250,000	\$554,900	\$54,300,000
Underground - Route A	\$387,800	\$59,510,000	\$1,171,000	\$0	\$267,100	\$61,340,000
Triangular Post - Route B	\$5,219,000	\$60,380,000	\$1,496,000	\$3,450,000	\$614,300	\$71,160,000
Split-Phase - Route B	\$329,300	\$59,460,000	\$1,496,000	\$3,450,000	\$676,300	\$65,410,000
Underground - Route B	\$435,400	\$70,820,000	\$1,394,000	\$0	\$341,900	\$72,990,000
Triangular Post - Route C	\$2,982,000	\$99,030,000	\$2,453,000	\$4,650,000	\$989,100	\$110,100,000
Split-Phase - Route C	\$188,200	\$97,510,000	\$2,453,000	\$4,650,000	\$1,090,000	\$105,900,000
Underground - Route C	\$248,800	\$114,300,000	\$2,286,000	\$0	\$530,800	\$117,300,000

1



**Figure 8.36: Stacked Bar Chart of Equivalent Cost Components
for the New 115 kV Transmission Line Scenario A**
(3% Discount Rate, 80% of TPC Financed at 10%)



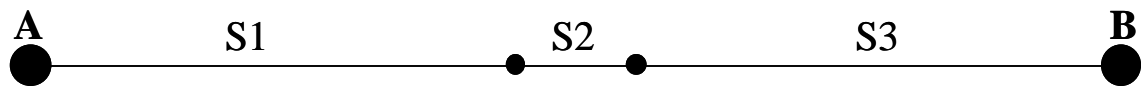
**Figure 8.37: Stacked Bar Chart of Equivalent Cost Components
for 115kV New Transmission Line Scenario A**
(3% Discount Rate, TPC Not Financed)

1 **8.7 New Transmission Lines – Scenario B**

2 Note: The detailed model specifications of this scenario can be found in the
3 ANALYTICA® Model named “TN-115-B.ana.”

4 **Basic Layout:**

5 In this scenario, a new 115 kV transmission line with a maximum ampacity of
6 1000 A is built to connect two points, A and B. The total length of the line is 10.5 miles
7 and is divided into three segments as shown in Figure 8.38.



8 **Figure 8.38: Routes and route segments for 115 kV New**
9 **Transmission Line Scenario B**

10 The length of each individual segment and the assumed population for each
11 segment are given in Table 8.30.

12 **Table 8.30: Length and Population Characteristics of Route Segments**
13 **for 115 kV New Transmission Line Scenario B**

Segment	Length (in miles)	Population (total on both sides)	Number of Adjacent Homes per Mile (both sides)
S1	5	2400	40
S2	0.5	500	10
S3	5	1200	20

14 Thus, the line affects a total population of 4,100 people within 350 feet of the line
15 and about 300 homes adjacent to it.

16
17 Three different line configurations are considered:

- 19 • Triangular Post Configuration (Conductor 1272 AAC; Narcissus);
- 20 • Split-Phase with Horizontal Post Construction (Conductor 795 AAC; Arbutus;
21 a smaller conductor is used since with this configuration two conductors will
22 carry the load of one phase, so the ampacity of each is 500 A).
- 23 • Underground (Solid Dielectric).

In addition, this model analyzes the impact of different ROWs. To this end, each of the three configurations was combined with either a 50' ROW or a 100' ROW to define the following six alternatives:

- Triangular Post – 50' ROW
- Split-Phase – 50' ROW
- Underground – 50' ROW
- Triangular Post – 100' ROW
- Split-Phase – 100' ROW
- Underground – 100' ROW

Exposure and Exposure Reduction:

Exposures were calculated over a distance of 300' on each side of the line. The exposure profiles for TWA are given in Figure 8.39 for each of the three line configurations.

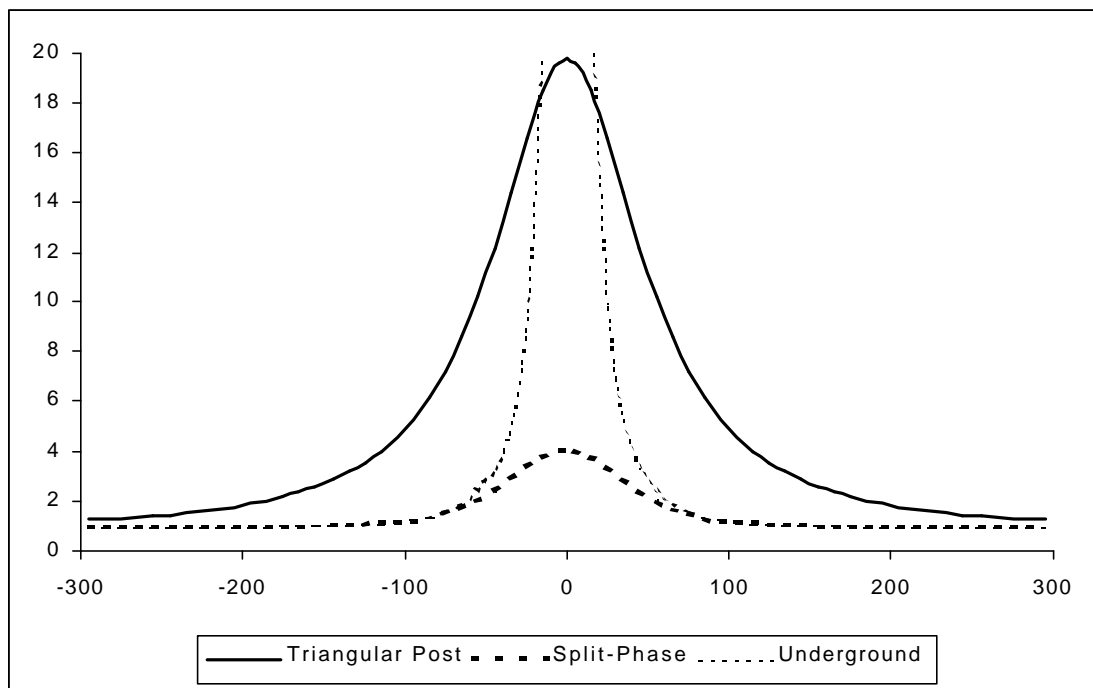


Figure 8.39: Exposure Profiles for Different Line Configurations for 115 kV New Transmission Line Scenario B (Metric: TWA)

The exclusion zones in this scenario are set to a total width of 100' and 200', respectively. The corresponding exposure reduction (taking the Triangular Post configuration with a 50' ROW as the standard of comparison) as calculated in the ANALYTICA[®] model is shown in Table 8.31.

**Table 8.31: Relative Exposure Reduction for 115 kV
New Transmission Line Scenario B**

Alternatives	Effects Functions						
	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
Triangular Post - 50 ft. ROW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Split Phase - 50 ft. ROW	93.83%	97.61%	100.00%	99.71%	95.06%	99.77%	99.65%
Underground - 50 ft. ROW	91.84%	96.03%	100.00%	99.71%	92.34%	99.68%	99.53%
Triangular Post - 100 ft. ROW	46.21%	51.48%	82.85%	96.88%	26.28%	76.67%	96.84%
Split Phase - 100 ft. ROW	98.60%	99.96%	100.00%	100.00%	99.90%	99.99%	99.89%
Underground - 100 ft. ROW	97.85%	99.96%	100.00%	100.00%	99.88%	99.99%	99.84%

Overall Results

The equivalent costs of the major non-EMF criteria are shown in Tables 8.32 and 8.33. Table 8.32 shows the discounted and financed case, Table 8.33 shows the discounted and unfinanced case. The main observation about these tables are that the direct costs dominate the results and that increasing the ROW and undergrounding increase the costs substantially.

Table 8.32: Equivalent Cost for the 115kV New Transmission Line Scenario B
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Cost	Outages	Property Values	Other	Total
Triangular Post - 50ft ROW	\$94,010,000	\$1,256,000	\$4,575,000	\$307,400	\$100,148,400
Split-Phase - 50ft ROW	\$93,560,000	\$1,256,000	\$4,575,000	\$306,700	\$99,697,700
Underground - 50ft ROW	\$114,200,000	\$1,171,000	\$0	\$304,400	\$115,675,400
Triangular Post - 100ft ROW	\$177,200,000	\$1,256,000	\$4,575,000	\$307,400	\$183,338,400
Split-Phase - 100ft ROW	\$176,700,000	\$1,256,000	\$4,575,000	\$306,700	\$182,837,700
Underground - 100ft ROW	\$197,400,000	\$1,171,000	\$0	\$304,400	\$198,875,400

Table 8.33: Equivalent Cost for the 115kV New Transmission Line Scenario B
(3% Discount Rate, TPC not Financed)

Alternatives	Cost	Outages	Property Values	Other	Total
Triangular Post - 50ft ROW	\$50,170,000	\$1,256,000	\$4,575,000	\$307,400	\$56,308,400
Split-Phase - 50ft ROW	\$49,320,000	\$1,256,000	\$4,575,000	\$306,700	\$55,457,700
Underground - 50ft ROW	\$59,510,000	\$1,171,000	\$0	\$304,400	\$60,985,400
Triangular Post - 100ft ROW	\$92,130,000	\$1,256,000	\$4,575,000	\$307,400	\$98,268,400
Split-Phase - 100ft ROW	\$91,280,000	\$1,256,000	\$4,575,000	\$306,700	\$97,417,700
Underground - 100ft ROW	\$101,500,000	\$1,171,000	\$0	\$304,400	\$102,975,400

Sensitivity Analyses

Figure 8.40 shows the result of the two-way sensitivity analysis on p and RR assuming that 80% of the total project costs are financed at a 10% annual interest rate. The result is very simple: for all values of p and RR, the best alternative is use a 50 ft. ROW on each side of the line and to split phase the line. This occurs, because of the substantial costs of increasing the ROW to 100 feet and because split phasing reduces both line losses and potential EMF risks.

All other sensitivity analyses produced the same stable result: The 50 ft. ROW and split phasing are always preferred over all other alternatives, independent of whether or not the TPC is financed, whether or not property values are being considered, and whether one considers all health effects or only leukemia.

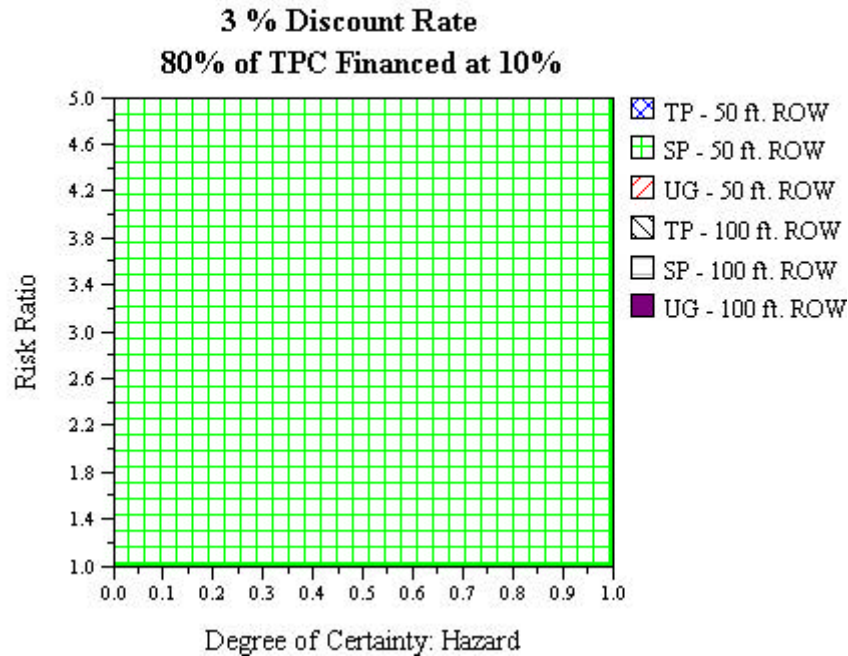


Figure 8.40: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the 115 New Transmission Line Scenario B
(All Health Endpoints, TPC Financed, Property Values Included)

An Illustrative Analysis Including EMF Health Effects

For illustration of specific results including EMF health effects, we chose $p=0.10$ and $RR=2$. Table 8.34 shows the equivalent costs of the major criteria including EMF health assuming that TPC is financed. Figure 8.39 shows the same information as a stacked bar chart. Table 8.41 and Figure 8.42 are the corresponding results assuming that TPC is not financed. Both tables and both graphs tell the same story: Direct cost (TPC, O&M and line losses) dominate the results. The larger the ROW, the more costly the line is. Split phasing is the best mitigation alternative both ROW conditions, because it substantially reduces health risks and has a lower direct cost, due to less line losses.

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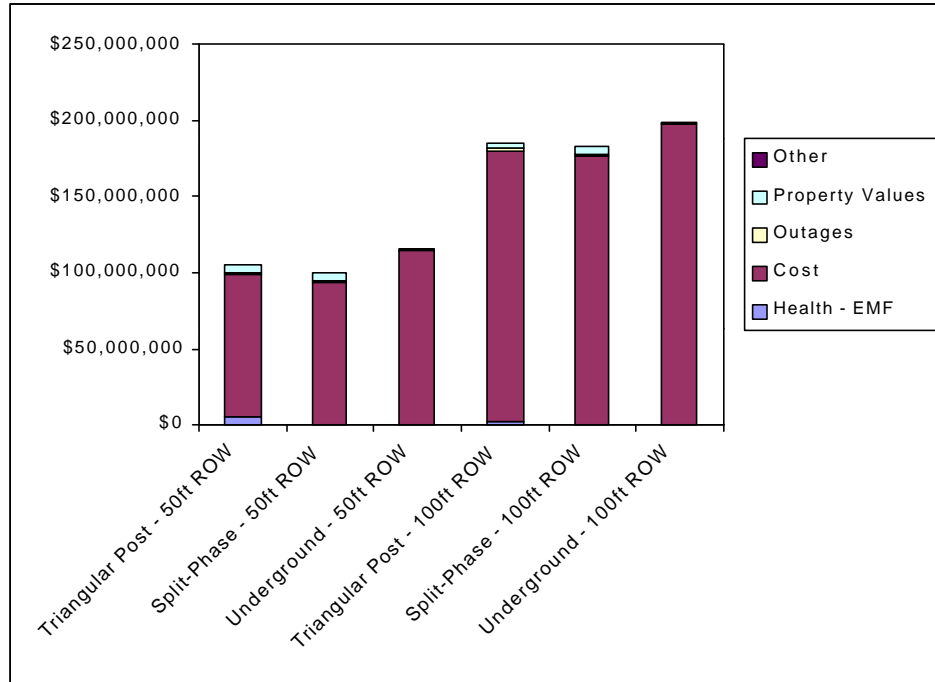
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Table 8.34: Equivalent Cost for the New 115kV Transmission Line Scenario B
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
Triangular Post - 50ft ROW	\$5,095,000	\$94,010,000	\$1,256,000	\$4,575,000	\$307,400	\$105,200,000
Split-Phase - 50ft ROW	\$321,500	\$93,560,000	\$1,256,000	\$4,575,000	\$306,700	\$100,000,000
Underground - 50ft ROW	\$425,000	\$114,200,000	\$1,171,000	\$0	\$304,400	\$116,100,000
Triangular Post - 100ft ROW	\$2,801,000	\$177,200,000	\$1,256,000	\$4,575,000	\$307,400	\$186,100,000
Split-Phase - 100ft ROW	\$72,660	\$176,700,000	\$1,256,000	\$4,575,000	\$306,700	\$183,000,000
Underground - 100ft ROW	\$111,800	\$197,400,000	\$1,171,000	\$0	\$304,400	\$199,000,000

Table 8.35: Equivalent Cost for the New 115 kV Transmission Line Scenario B
(3% Discount Rate, TPC Not Financed)

Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
Triangular Post - 50ft ROW	\$5,095,000	\$50,170,000	\$1,256,000	\$4,575,000	\$307,400	\$61,400,000
Split-Phase - 50ft ROW	\$321,500	\$49,320,000	\$1,256,000	\$4,575,000	\$306,700	\$55,780,000
Underground - 50ft ROW	\$425,000	\$59,510,000	\$1,171,000	\$0	\$304,400	\$61,410,000
Triangular Post - 100ft ROW	\$2,801,000	\$92,130,000	\$1,256,000	\$4,575,000	\$307,400	\$101,100,000
Split-Phase - 100ft ROW	\$72,660	\$91,280,000	\$1,256,000	\$4,575,000	\$306,700	\$97,490,000
Underground - 100ft ROW	\$111,800	\$101,500,000	\$1,171,000	\$0	\$304,400	\$103,100,000

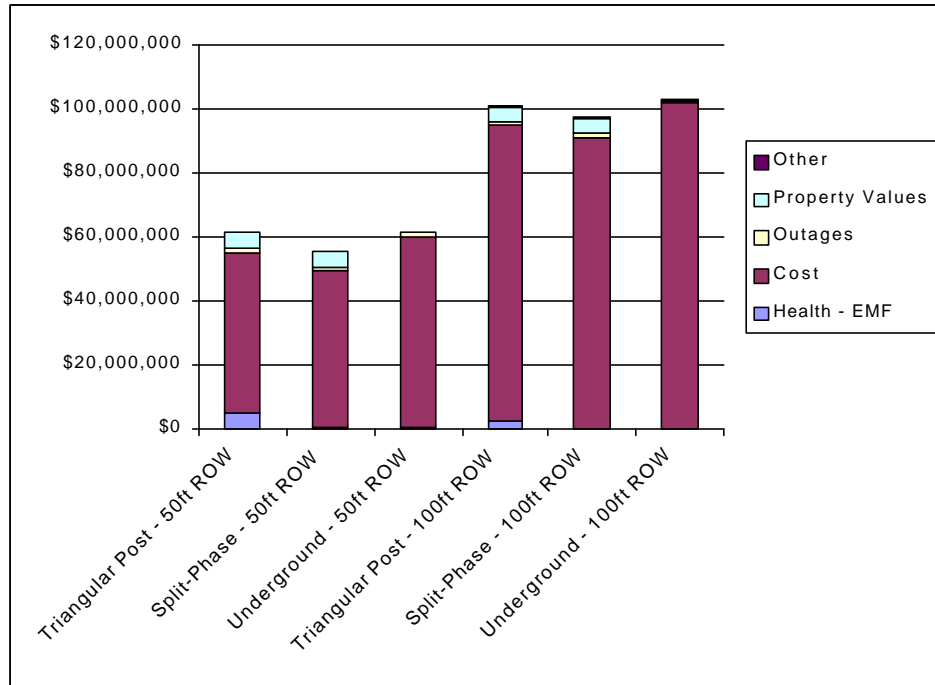


**Figure 8.41: Stacked Bar Chart of Equivalent Cost Components
for the New 115 kV Transmission Line Scenario B**
(3% Discount Rate, 80% of TPC Financed at 10%)

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**Figure 8.42: Stacked Bar Chart of Equivalent Cost Components
for 115kV Transmission Line Retrofit Scenario B**
(3% Discount Rate, TPC Not Financed)

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8.8 New Transmission Lines – Scenario C

Note: The detailed model specifications of this scenario can be found in the ANALYTICA® Model named “TN-115-C.ana.”

Basic Layout:

In this scenario, a new 115 kV transmission line with a maximum ampacity of 1000 A is built to connect two points, A and B, with an existing 33kV Delta configured distribution line in place. The total length of the line is 10.5 miles and is divided into three segments as shown in Figure 8.43.

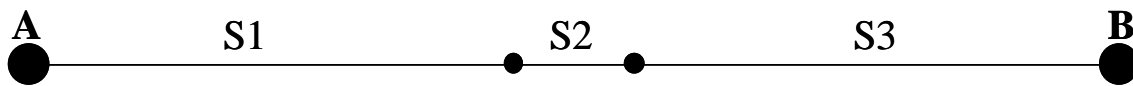


Figure 8.43: Routes and route segments for 115 kV New Transmission Line Scenario C

The length of each individual segment and the assumed population for each segment are given in Table 8.36.

Table 8.36: Length and Population Characteristics of Route Segments for 115 kV New Transmission Line Scenario C

Segment	Length (in miles)	Population (total on both sides)	Number of Adjacent Homes per Mile (both sides)
S1	5	2400	40
S2	0.5	500	10
S3	5	1200	20

Thus, the line affects a total population of 4,100 people in about 1,370 homes within 350 feet of the line. About 300 of these homes are adjacent to the line.

Three alternative line configurations are considered:

- Triangular Post Configuration (Conductor 1272 AAC; Narcissus);
- Split-Phase with Horizontal Post Construction (Conductor 795 AAC; Arbutus; a smaller conductor is used since with this configuration two conductors will carry the load of one phase, so the ampacity of each is 500 A).
- Underground (Solid Dielectric).

Exposure and Exposure Reduction:

Exposures were calculated over a distance of 300' on each side of the line. The exposure profiles for TWA are given in Figure 8.44 for each of the four line configurations.

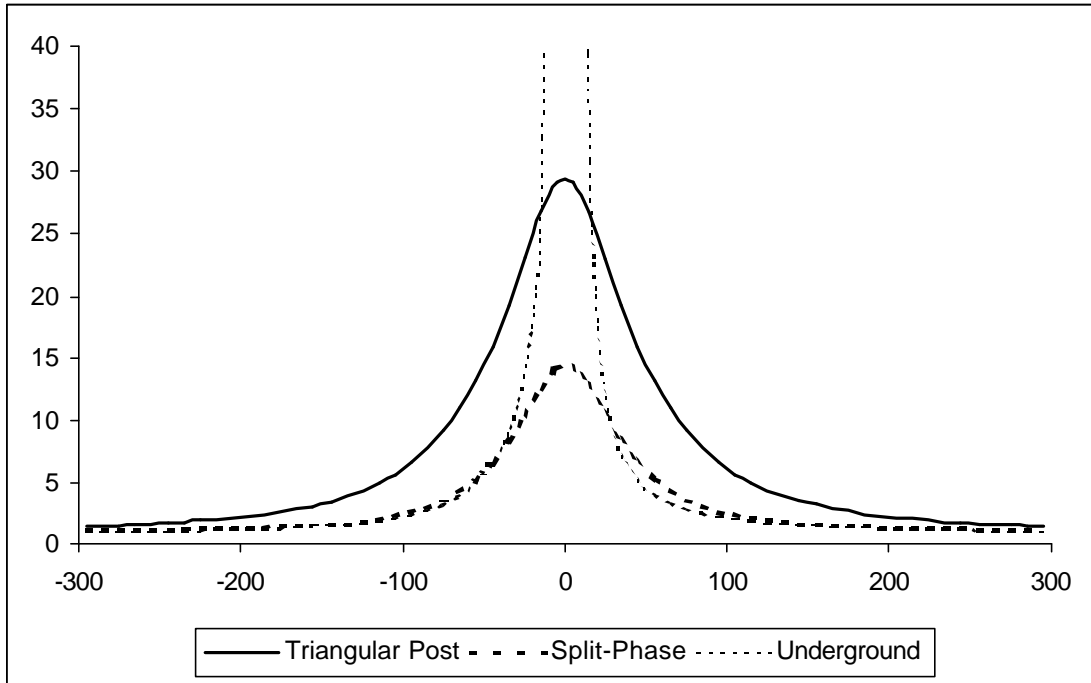


Figure 8.44: Exposure Profiles for Different Line Configurations for 115 kV New Transmission Line Scenario C (Metric: TWA)

The exclusion zone in this scenario is set to a total width of 100'. Thus, the exposed population is at least 50' from the line. The corresponding exposure reduction (taking the Horizontal Post configuration as the standard of comparison) as calculated in the ANALYTICA[®] model is shown in Table 8.37.

Table 8.37: Relative Exposure Reduction for 115 kV New Transmission Line Scenario C

Alternatives	Effects Functions						
	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
Triangular Post	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Split Phase	70.12%	73.80%	88.03%	97.09%	59.21%	83.49%	96.62%
Underground	73.88%	78.34%	92.00%	97.87%	64.10%	88.79%	97.62%

Overall Results

The equivalent costs of the major non-EMF criteria are shown in Tables 8.38 and 8.39. Table 8.38 shows the discounted and financed case, Table 8.39 shows the discounted and unfinanced case. The main observation about these tables are that the direct costs dominate the results and that split phasing is the least expensive alternative, followed by the triangular post design, followed, as a distant third, undergrounding.

Table 8.38: Equivalent Cost for the 115kV New Transmission Line Scenario C
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Cost	Outages	Property Values	Other	Total
Triangular Post	\$95,380,000	\$1,256,000	\$4,575,000	\$307,400	\$101,518,400
Split-Phase	\$94,930,000	\$1,256,000	\$4,575,000	\$306,700	\$101,067,700
Underground	\$114,800,000	\$1,171,000	\$0	\$304,400	\$116,275,400

Table 8.39: Equivalent Cost for the 115kV New Transmission Line Scenario C
(3% Discount Rate, TPC not Financed)

Alternatives	Cost	Outages	Property Values	Other	Total
Triangular Post	\$50,860,000	\$1,256,000	\$4,575,000	\$307,400	\$56,998,400
Split-Phase	\$50,010,000	\$1,256,000	\$4,575,000	\$306,700	\$56,147,700
Underground	\$59,800,000	\$1,171,000	\$0	\$304,400	\$61,275,400

Sensitivity Analyses

Figure 8.45 shows the results of the two-way sensitivity analysis on p and RR assuming that 80% of the total project costs are financed at a 10% annual interest rate. The result is very simple: for all values of p and RR, the best alternative is to split phase the line. This occurs, because the non-EMF costs of split phasing are the least expensive and because split phasing (with reverse phasing) is an effective method of reducing fields. Undergrounding is more effective, but even if one assumes that there is a health effect and that the risk ratio is 5, split phasing is still the preferred option, given the assumptions made in the model.

All other sensitivity analyses produced the same result: Split phasing is always preferred over all other alternatives, independent of whether or not the TPC is financed, whether or not property values are being considered, and whether one considers all health effects or only leukemia.

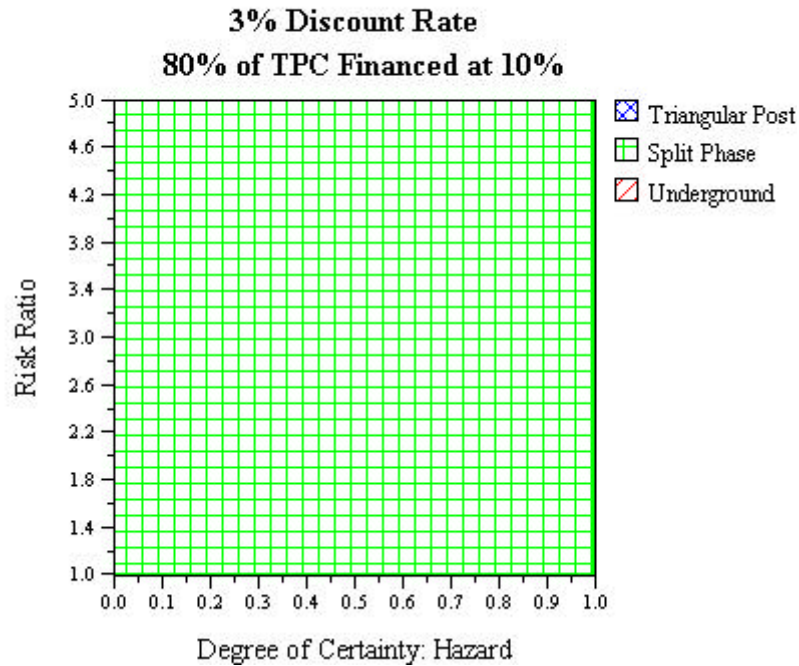


Figure 8.45: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the 115 New Transmission Line Scenario C
(All Health Endpoints, TPC Financed, Property Values Included)

An Illustrative Analysis Including EMF Health Effects

For illustration of specific results including EMF health effects, we chose $p=0.10$ and $RR=2$. Table 8.40 shows the equivalent costs of the major criteria including EMF health assuming that TPC is financed. Figure 8.46 shows the same information as a stacked bar chart. Table 8.41 and Figure 8.47 are the corresponding results assuming that TPC is not financed. Both tables and both graphs tell the same story: Direct cost (TPC, O&M and line losses) dominate the results. The larger the ROW, the more costly the line is. Split phasing is the best mitigation alternative for both ROW conditions, because it substantially reduces health risks and has a lower direct cost, due to less line losses.

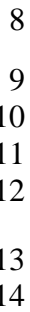
Table 8.40: Equivalent Cost for the New 115kV Transmission Line Scenario C
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

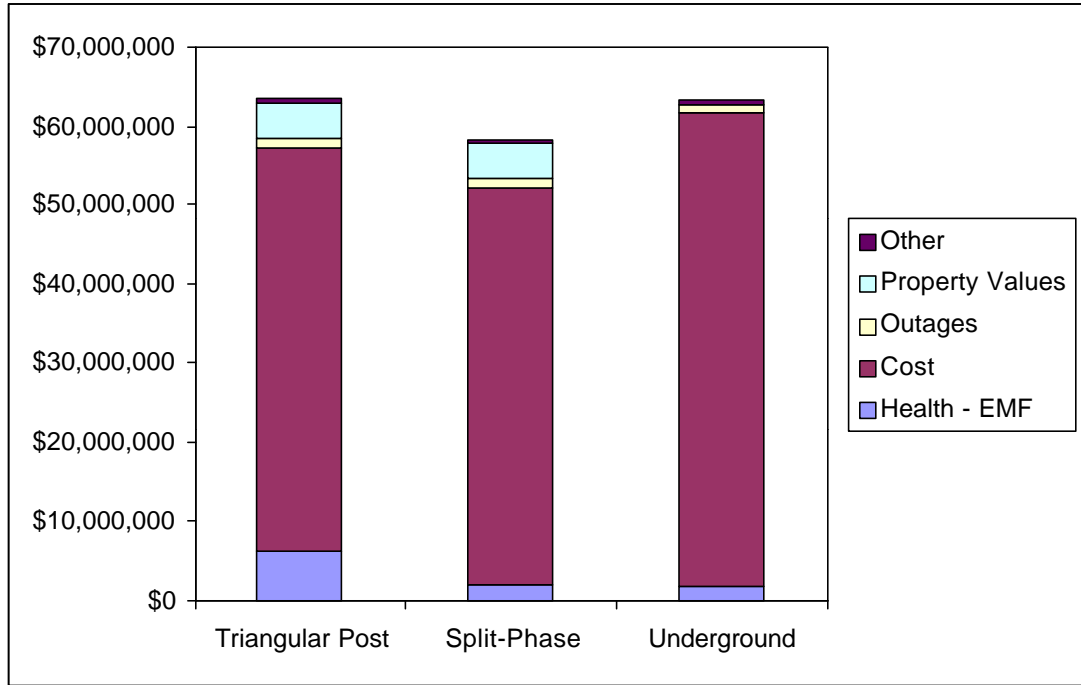
Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
Triangular Post	\$6,351,000	\$95,380,000	\$1,256,000	\$4,575,000	\$307,400	\$107,900,000
Split-Phase	\$2,066,000	\$94,930,000	\$1,256,000	\$4,575,000	\$306,700	\$103,100,000
Underground	\$1,806,000	\$114,800,000	\$1,171,000	\$0	\$304,400	\$118,100,000

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**Figure 8.47: Stacked Bar Chart of Equivalent Cost Components
for 115kV Transmission Line Retrofit Scenario C**
(3% Discount Rate, TPC Not Financed)

8.9 Other Transmission Line Scenarios

In this section we present results of exposure calculations for two special cases. First, we examine the exposure profiles for several configurations of the conductors in a solid dielectric underground design. Second, we examine the effects of building a new line in an existing grid with increasing load requirements over time. These calculations were made in response to specific stakeholder requests. We have not run Analytica models for these cases.

Alternative Conductor Configurations in Solid Dielectric Underground Designs

The conductors or “cables” of a solid dielectric design can be configured in several ways. If they are placed in ducts, then the ducts can be in a vertical, a horizontal, or a triangular configuration. All three are used in California. One advantage of the triangular is that often there are four ducts, with a “spare” duct available if needed. PG&E sometimes use this configuration.

Calculations were done to compare the field profiles of these three configurations. The phase to phase spacing for the vertical and horizontal configurations was 1.25'. The horizontal and vertical spacings were both set at 1.25' for the triangular configuration. In all cases, the topmost conductor is 3.5' below grade. The current magnitudes were calculated assuming an ampacity of 600 Amps, with a load factor of 0.33, resulting in approximately 320 Amps. For the sake of comparison, the fields for a split phase design with the same per phase current have been calculated. The structure type is Hexagonal Split, ID 10310, with D1 = 10.6' and 6.5' and H=55'. With 6 conductors, the typical current in each conductor is 160 Amps (320 Amps per phase). In all cases, the background fields were considered to be zero, to provide a more accurate comparison between the different cases.

Figure 8.48 shows the three underground and the split phase calculated fields. The two “in line” configurations, vertical and horizontal, give very similar results for the field magnitude, with the vertical slightly lower due to the fact that the lower conductors are more deeply buried. The triangular configuration is the best of the three underground cases, as the two furthest conductors are 1.77' apart rather than 2.5' apart as for the horizontal and vertical configurations. The split phase design is clearly the winner here. This is due to two factors: the conductors are further away, and the fields drop off as $1/R^3$ rather than $1/R^2$ as for the 3-conductor underground designs.

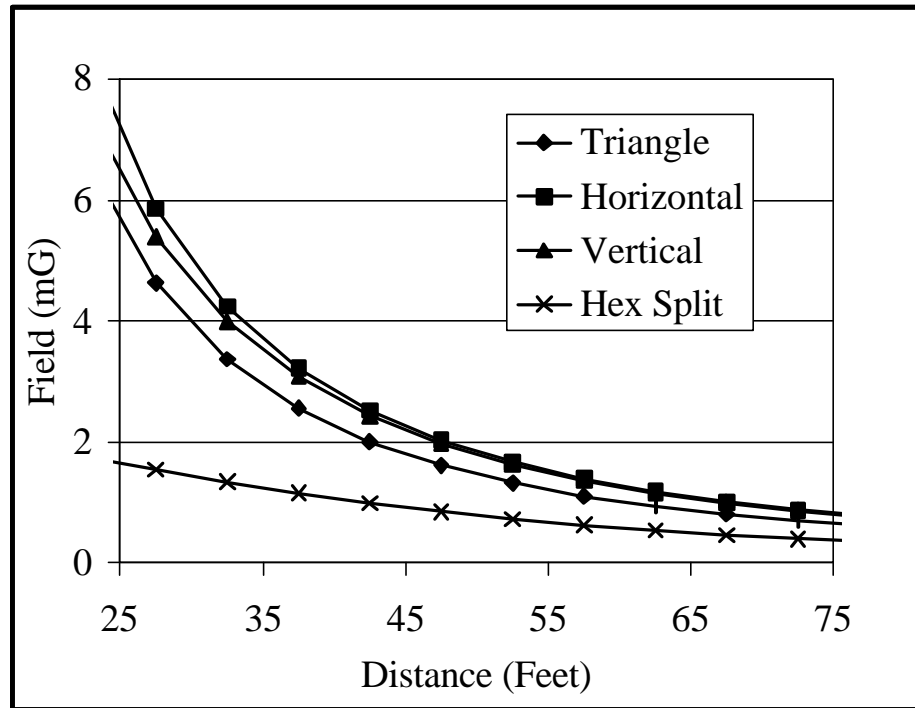


Figure 8.48: Comparison of Three Underground Solid Dielectric Configurations and a Hexagonal Split Configuration.

Modeling Lines in the Same Grid and Increased Load Requirements Over Time

This section explores the exposure impact of building a new transmission line on the loading of existing lines within a grid? In addition, it examines the impact of increases in future loading on existing lines.

In this scenario, we assume that two substations, Substation A and Substation B, are part of a 115 kV grid. They are 10 miles apart, and the interconnect traverses a variety of land types, including rural, open, suburban, and one school. The area served by substation B is rapidly growing, resulting in significantly increased demand over time. At present, the lines are operating with a typical loss factor of 0.5, and near capacity during the summer months. Due to the composition of the overall grid, the only reasonable path to significantly increase the capacity at B is via the interconnect with A.

We further assume that the existing towers are steel lattice, and were built about 50 years ago. The conductors are rated for an ampacity of 600 Amps. These towers were not originally built with future upgrades in mind, so that to get further capacity either these towers will have to be replaced or an additional line will have to be built. There is room on the ROW for another line.

1 Presently, the typical loading of the line is about $115,000 * (0.7) * 600 * 3 * 2 =$
2 290 MVA. 0.7 is estimated from the loss factor $(0.7^2) = 0.49$. 3 is the number of
3 conductors, 2 is number of circuits.

4 Option A: The ampacity of the existing circuits are increased by rebuilding the
5 line using 1,000 Amp rated conductors. The typical load will then be $290 * (1000/600) =$
6 483 MVA. This should be adequate for 10 years, at which time the projections are that
7 the lines will again be loaded to capacity.

8 Option B: Build another Double Circuit line, say a 600 ampacity line, which
9 could be upgraded in the future. This line will serve twice the load of the base case, a
10 total of 580 MVA, which is projected to be adequate for at least 15 years.

11 Option C: Build a single circuit underground line to supplement the overhead
12 double circuit. This could not be readily upgraded in the future, so that a 1,000-amp
13 design is chosen. Because the existing overhead line would remain in place, there would
14 be no property value impact due to this option. Using this option 483 MVA can be
15 served, as in option A.

16 Option D: Build an underground line as in option C, and underground the existing
17 line. Given using larger cables is not a major cost factor, all cables are assumed to be
18 rated for 1,000 amps. The total load served would be 1.5 times option A, since there are
19 now 3 rather than 2 circuits, so that 724.5 MVA can be supplied. In this case, there could
20 be a property value impact, depending on the assumptions made.

21 The base and four options are compared in Figure 8.49. A 0.33 loss factor is
22 assumed. Thus, for example, the difference between base and option A, which is simply an
23 increase from 600 to 1000 Amp rated conductors, results in a scaling of the fields by 67%.

24 Our point in giving the above model is not to make any recommendations, but to
25 give an idea of how multiple lines in the same grid and future load changes can be
26 modeled. In this case the various options are not directly comparable: if a second line is
27 built, then there is more load capacity and more flexibility in the future. If the first line is
28 upgraded, then less capacity is added and there is less flexibility in the future. These
29 types of considerations could be included if so desired.

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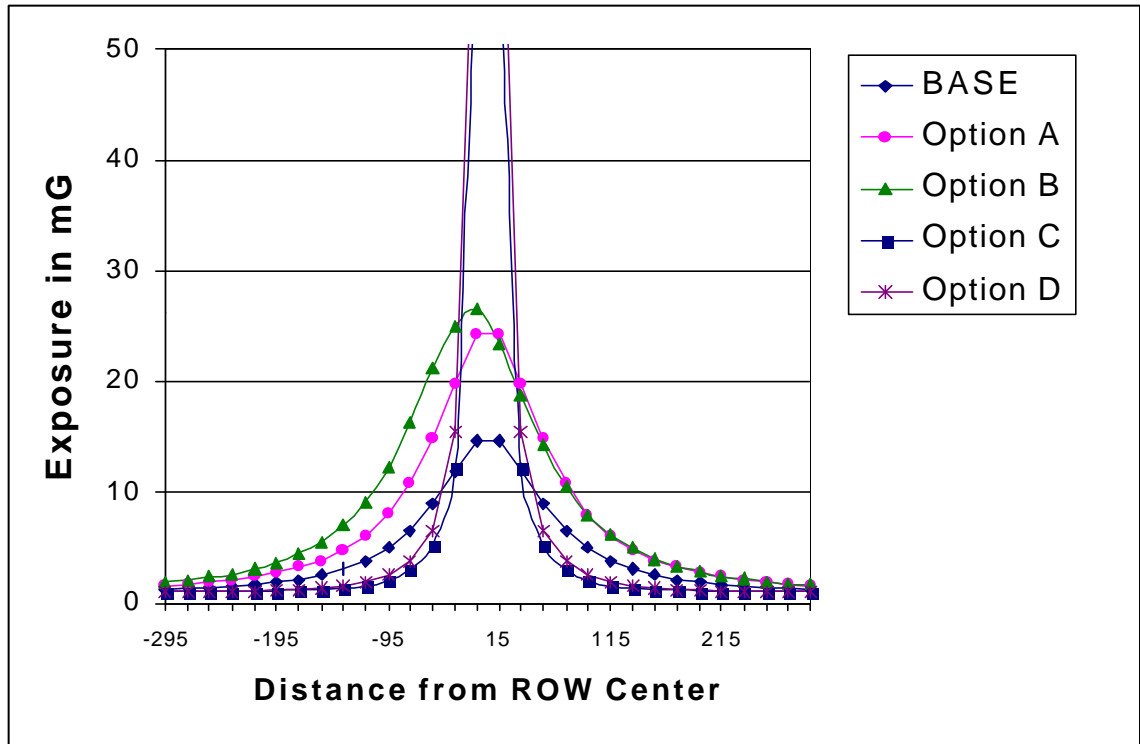


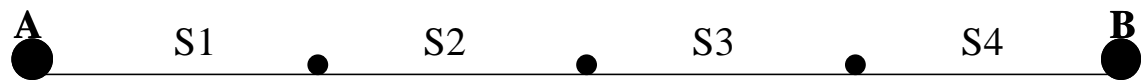
Figure 49: Exposure Profiles for the Base Case and Four Options for Upgrading and Existing Powerline
 (Note that the field profiles are not symmetrical, as the load originates more on one side of the ROW depending on the option)

1 **8.10 Distribution Line Retrofitting – Scenario A**

2 Note: The detailed model specifications of this scenario can be found in the
3 ANALYTICA® Model named “DR-A.ana.”

4 **Basic Layout:**

This scenario describes a 12 kV three-wire distribution line retrofit. The line is a radial feeder, starting at a substation and terminating four miles away. The existing line is on 40’ wooden poles and runs through a suburban environment. The overall length of this line is divided into four segments of different loading.



7 **Figure 8.50: Basic Layout of Distribution Line Retrofit Scenario A**

8

9 The length of each individual segment and the assumed population for each
10 segment are given in Table 8.42.

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Table 8.42: Length and Population Characteristics of Route Segments for the Distribution Line Scenario A

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Segment	Length (in miles)	Population (total on both sides)	Number of Adjacent Homes per Mile (both sides)
S1	1	500	100
S2	1	500	100
S3	1	500	100
S4	1	500	100

13

14 Thus, the overall length of the line is 4 miles. The line affects a total of 2,000
15 people within 160 ft. of the line and 400 homes adjacent to the line.

1 Four different line configurations are considered:

2

- 3 • No Change (existing pole configuration)
- 4 • Convert to Compact Delta
- 5 • Raise Pole Height
- 6 • Underground (Solid Dielectric)

7 In addition, the potential retrofits were considered for the whole length of the line
8 and for the first segment (with the highest load) only. Thus, there are seven alternatives:

9

- 10 • No Change
- 11 • Compact Delta – All Segments
- 12 • Raise Pole Height – All Segments
- 13 • Underground – All Segments
- 14 • Compact Delta – Segments S1 only
- 15 • Raise Pole Height – Segment S1 only
- 16 • Underground – Segment S1 only

17

18 ***Exposure and Exposure Reduction:***

19 Exposures were calculated over a distance of 160' on each side of the line. The
20 exposure profiles for TWA are given in Figure 8.51 for one of the line segments. The
21 exposure profiles for the other line segments look similar, but show different peaks. For
22 example, the peak for “No Change” is about 13 mG for the first segment, 9 for the second
23 segment (shown), 6 for the third segment, and 4 for the fourth segment.

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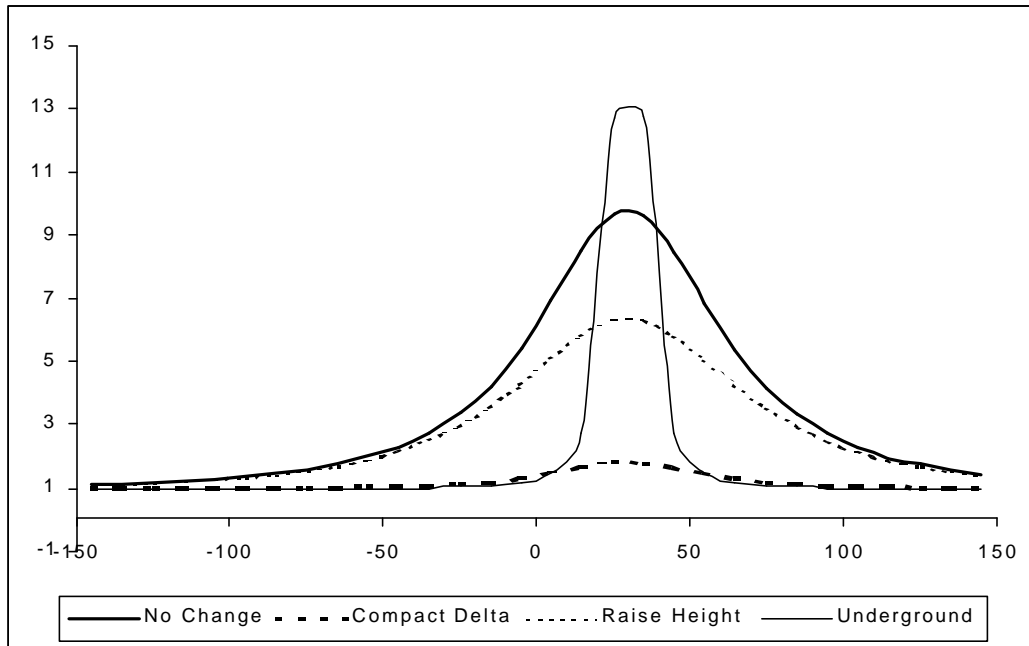


Figure 8.51: Exposure Profile (TWA) for the Distribution Line Retrofit Scenario A

The exclusion zone in this scenario is set to a total width of 100'. Thus, the exposed population is at least 50' from the line. The corresponding exposure reduction (taking the Horizontal Post configuration as the standard of comparison) as calculated in the ANALYTICA[®] model is shown in Table 8.43.

Table 8.43: Relative Exposure Reduction for the Distribution Line Retrofit Scenario A

Alternatives	Effects Function						
	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
No Change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Compact DELTA - All	94.74%	99.69%	100.00%	99.52%	99.56%	99.85%	97.45%
Raise Height - All	20.00%	28.56%	56.02%	78.57%	19.18%	50.62%	76.02%
Underground - All	96.99%	99.74%	100.00%	99.05%	99.69%	99.92%	98.67%
Compact DELTA - Segment	41.50%	48.77%	65.56%	83.81%	43.66%	61.66%	81.29%
Raise Height - Segment	7.91%	10.95%	32.40%	71.90%	4.22%	26.65%	70.92%
Underground - Segment	42.63%	48.81%	66.08%	83.81%	43.75%	61.74%	81.87%

Overall Results

The equivalent costs of the major non-EMF criteria are shown in Tables 8.44 and 8.45. Table 8.44 shows the discounted and financed case, Table 8.45 shows the discounted and unfinanced case. Overall, the least expensive alternative is not to change the line.

Table 8.44: Equivalent Cost for the Distribution Line Retrofit Scenario A
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Cost	Outages	Property Values	Other	Total
No Change	\$656,500	\$348,500	\$0	\$101,800	\$1,106,800
Compact DELTA - All	\$937,400	\$348,500	\$0	\$102,000	\$1,387,900
Raise Height - All	\$1,327,000	\$348,500	\$0	\$102,100	\$1,777,600
Underground - All	\$7,006,000	\$254,800	-\$3,000,000	-\$59,910	\$4,200,890
Compact DELTA - Segment	\$726,700	\$348,500	\$0	\$101,800	\$1,177,000
Raise Height - Segment	\$824,000	\$348,500	\$0	\$101,900	\$1,274,400
Underground - Segment	\$2,264,000	\$325,100	-\$750,000	\$61,380	\$1,900,480

Table 8.45: Equivalent Cost for the Distribution Line Retrofit Scenario A
(3% Discount Rate, TPC not Financed)

Alternatives	Cost	Outages	Property Values	Other	Total
No Change	\$656,500	\$348,500	\$0	\$101,800	\$1,106,800
Compact DELTA - All	\$798,200	\$348,500	\$0	\$102,000	\$1,248,700
Raise Height - All	\$994,500	\$348,500	\$0	\$102,100	\$1,445,100
Underground - All	\$3,936,000	\$254,800	-\$3,000,000	-\$59,910	\$1,130,890
Compact DELTA - Segment	\$691,900	\$348,500	\$0	\$101,800	\$1,142,200
Raise Height - Segment	\$741,000	\$348,500	\$0	\$101,900	\$1,191,400
Underground - Segment	\$1,497,000	\$325,100	-\$750,000	\$61,380	\$1,133,480

Sensitivity Analyses

Figure 8.52 shows the results of the two-way sensitivity analysis on p and RR assuming that 80% of the total project costs are financed at a 10% annual interest rate. The “No Change” alternative is preferred for fairly low values of p and RR, followed by the alternative “Compact Delta – Segment.” For most higher values of p and RR, the preferred alternative is “Compact Delta – All.”

Figure 8.53 shows the same sensitivity analysis, when TPC is not financed. In this case, the “No Change” alternative is preferred only for very small values of p and RR. For most of the range of p and RR, the preferred alternative is to underground the line, primarily because of the property values benefits. When ignoring the property value benefits, the results look similar to Figure 8.52 (see Figure 8.54). When considering leukemia only, “No Change” becomes the preferred alternative for a slightly larger region of p and RR values (Figure 8.55). When financing is dropped from consideration (Figure 8.56) undergrounding dominates again.

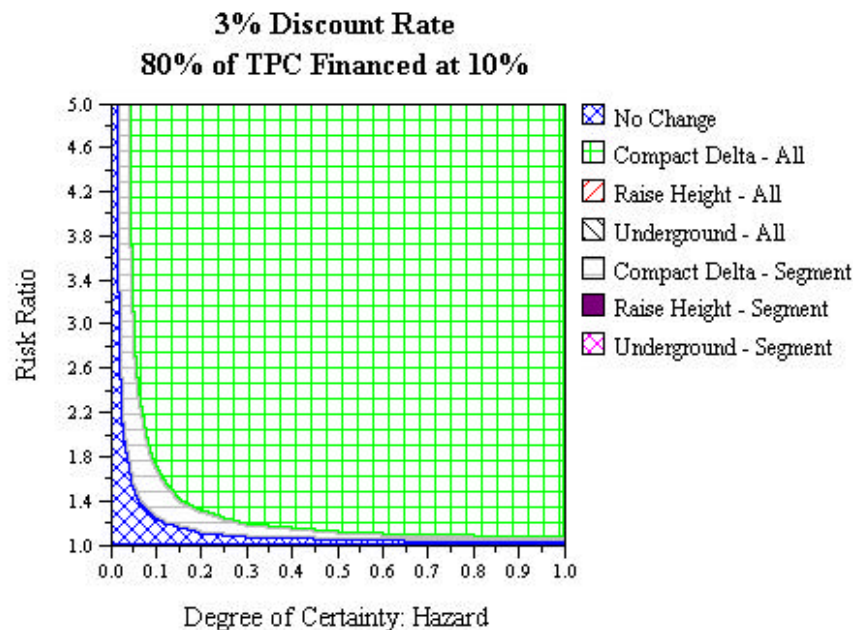


Figure 8.52: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Distribution Line Retrofit Scenario A
(All Health Endpoints, TPC Financed, Property Values Included)

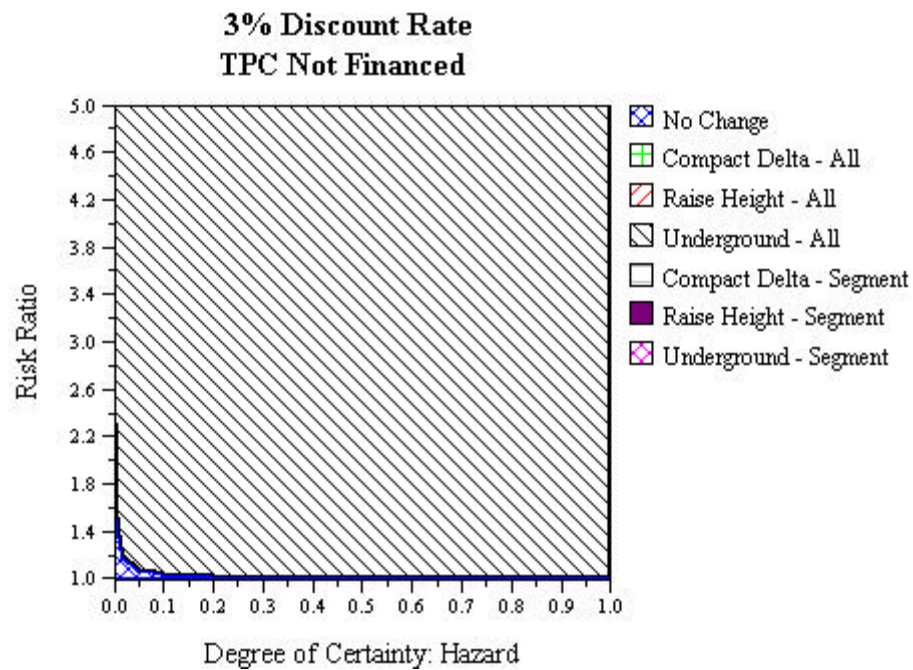


Figure 8.53: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Distribution Line Retrofit Scenario A
(All Health Endpoints, TPC Not Financed, Property Values Included)

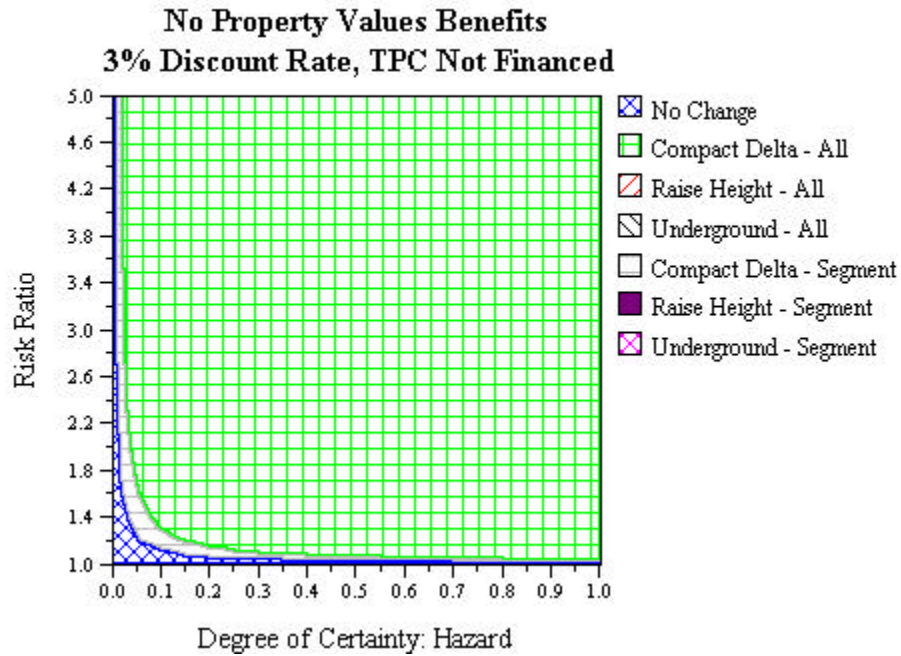


Figure 8.54: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Distribution Line Retrofit Scenario A
(All Health Endpoints, TPC Not Financed, Property Values Not Included)

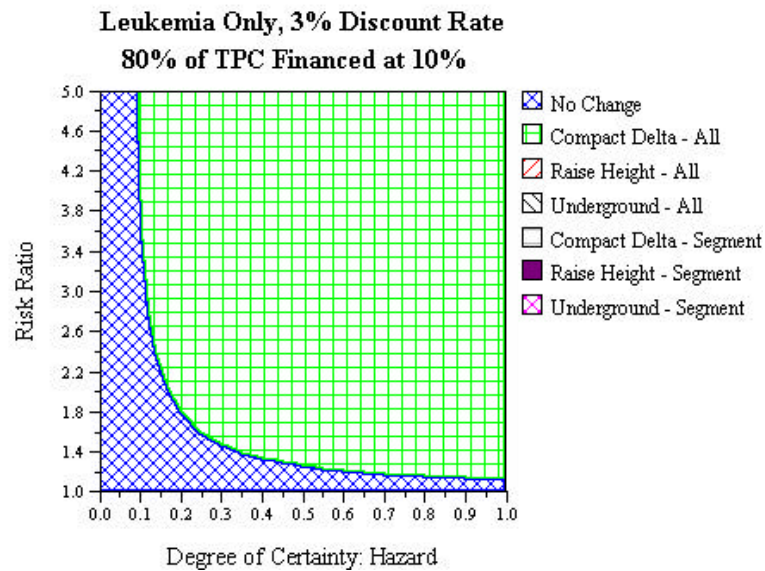


Figure 8.55: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Distribution Line Retrofit Scenario A
(Leukemia Only, TPC Financed, Property Values Included)

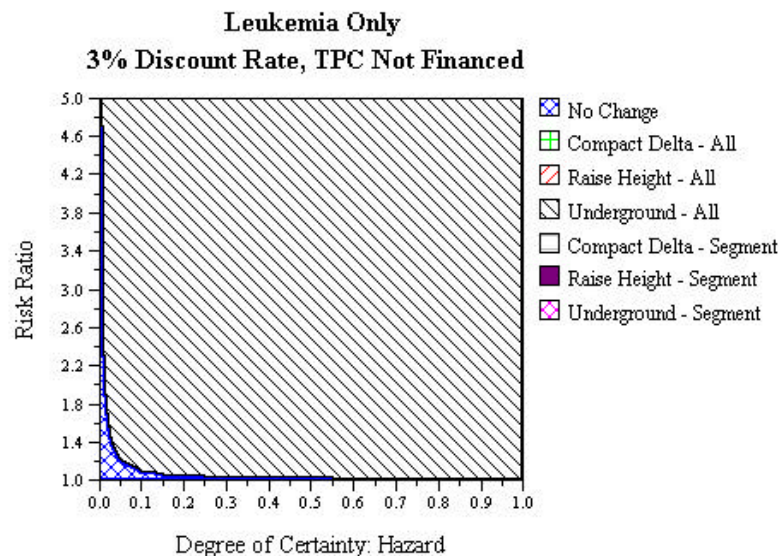


Figure 8.56: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Distribution Line Retrofit Scenario A
(Leukemia Only, TPC Not Financed, Property Values Included)

An Illustrative Analysis Including EMF Health Effects

For illustration of specific results including EMF health effects, we chose $p=0.10$ and $RR=2$. Table 8.45 shows the equivalent costs of the major criteria including EMF health assuming that TPC is financed. Figure 8.57 shows the same information as a stacked bar chart. Table 8.46 and Figure 8.58 are the corresponding results assuming that TPC is not financed. When TPC is financed, the “Compact Delta” alternative is best, because it reduced EMF health risks at a fairly low cost. When TPC is not financed, undergrounding just beats compact delta, primarily because of its property values benefits.

Table 8.45: Equivalent Cost for the Distribution Line Retrofit Scenario A
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
No Change	\$810,500	\$656,500	\$348,500	\$0	\$101,800	\$1,917,000
Compact DELTA - All	\$42,680	\$937,400	\$348,500	\$0	\$102,000	\$1,431,000
Raise Height - All	\$648,400	\$1,327,000	\$348,500	\$0	\$102,100	\$2,426,000
Underground - All	\$24,420	\$7,006,000	\$254,800	-\$3,000,000	-\$59,910	\$4,225,000
Compact DELTA - Segment	\$474,100	\$726,700	\$348,500	\$0	\$101,800	\$1,651,000
Raise Height - Segment	\$746,300	\$824,000	\$348,500	\$0	\$101,900	\$2,021,000
Underground - Segment	\$465,000	\$2,264,000	\$325,100	-\$750,000	\$61,380	\$2,366,000

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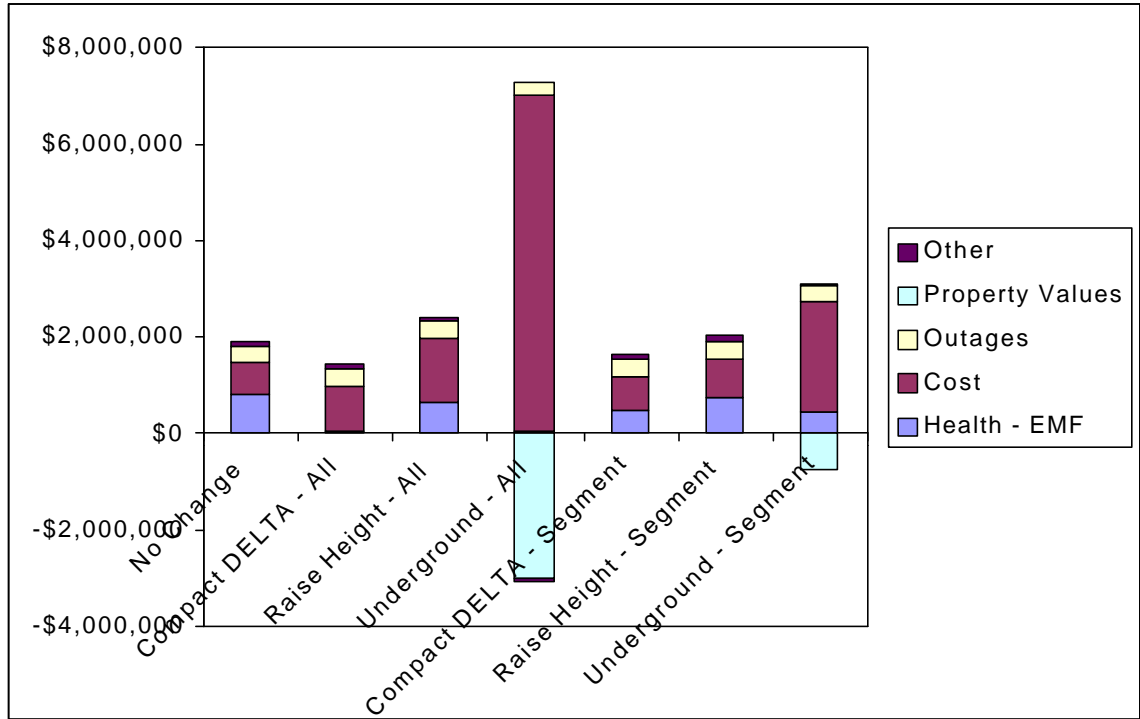
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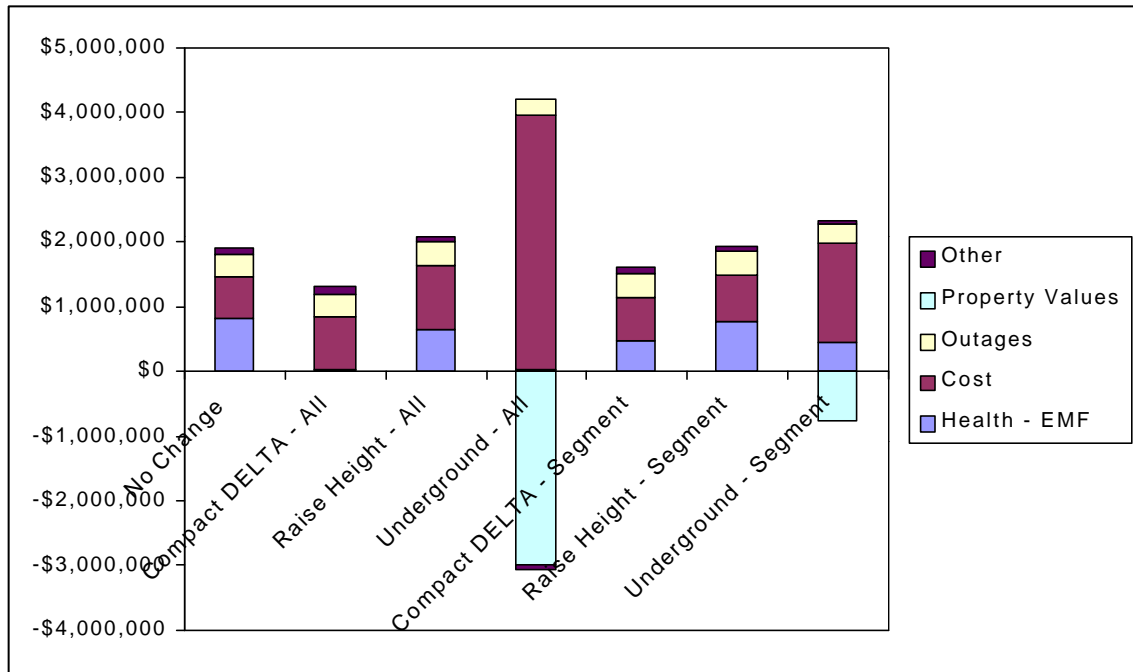
Table 8.46: Equivalent Cost for the Distribution Line Retrofit Scenario A
(3% Discount Rate, TPC Not Financed)

Alternatives	Health - EMF	Cost	Outages	Property		Total
				Values	Other	
No Change	\$810,500	\$656,500	\$348,500	\$0	\$101,800	\$1,917,000
Compact DELTA - All	\$42,680	\$798,200	\$348,500	\$0	\$102,000	\$1,291,000
Raise Height - All	\$648,400	\$994,500	\$348,500	\$0	\$102,100	\$2,094,000
Underground - All	\$24,420	\$3,936,000	\$254,800	-\$3,000,000	-\$59,910	\$1,155,000
Compact DELTA - Segment	\$474,100	\$691,900	\$348,500	\$0	\$101,800	\$1,616,000
Raise Height - Segment	\$746,300	\$741,000	\$348,500	\$0	\$101,900	\$1,938,000
Underground - Segment	\$465,000	\$1,497,000	\$325,100	-\$750,000	\$61,380	\$1,598,000



**Figure 8.57: Stacked Bar Chart of Equivalent Cost Components
for the Distribution Line Retrofit Scenario A**
(3% Discount Rate, 80% of TPC Financed at 10%)

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**Figure 8.58: Stacked Bar Chart of Equivalent Cost Components
for the Distribution Line Retrofit Scenario A
(3% Discount Rate, TPC Not Financed)**

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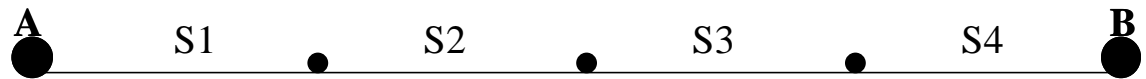
1 **8.11 Distribution Line Retrofitting – Scenario B**

2 Note: The detailed model specifications of this scenario can be found in the
3 ANALYTICA® Model named “DR-B.ana.”

4 ***Basic Layout:***

 This scenario describes a 12 kV four-wire distribution line retrofit. The line is a radial feeder, starting at a substation and terminating four miles away. The primary of the existing line is connected to a neutral. The line runs through a suburban environment. The overall length of this line is divided into four segments of different loading.

5
6
7 **Table 8.47: Loading Characteristics of Different Line Segments in Distribution Line**
8 **Retrofit Scenario A**



11 **Figure 8.59: Basic Layout of Distribution Line Retrofit Scenario B**

12
13 The length of each individual segment and the assumed population for each
14 segment are given in Table 8.48.

Table 8.47: Length and Population Characteristics of Route Segments for the
 Distribution Line Scenario B

15

Segment	Length (in miles)	Population (total on both sides)	Number of Adjacent Homes Mile (both sides) per
S1	1	500	100
S2	1	500	100
S3	1	500	100
S4	1	500	100

16

1 Thus, the overall length of the line is 4 miles. The line affects a total of 2,000
2 people within 160 ft. and 400 homes adjacent to it.

3 Four different line configurations are considered:

- 4 • No Change (existing pole configuration)
- 5 • Convert to Compact Delta
- 6 • Raise Pole Height
- 7 • Underground (Solid Dielectric)
- 8 • Insert Dielectric Couplers

9
10 In addition, the potential retrofits were considered for the whole length of the line
11 and for the first segment (with the highest load) only. Thus, there are seven alternatives:

- 12
13 • No Change
- 14 • Compact Delta – All Segments
- 15 • Raise Pole Height – All Segments
- 16 • Underground – All Segments
- 17 • Insert Dielectric Couplers - All
- 18 • Compact Delta – Segments S1 only
- 19 • Raise Pole Height – Segment S1 only
- 20 • Underground – Segment S1 only
- 21 • Insert DielectricCouplers – Segment 1 only

Exposure and Exposure Reduction:

Exposures were calculated over a distance of 160' on each side of the line. The exposure profiles for TWA are given in Figure 8.60 for the first line segment. The exposure profiles for the other line segments look similar, but show reduced peaks.

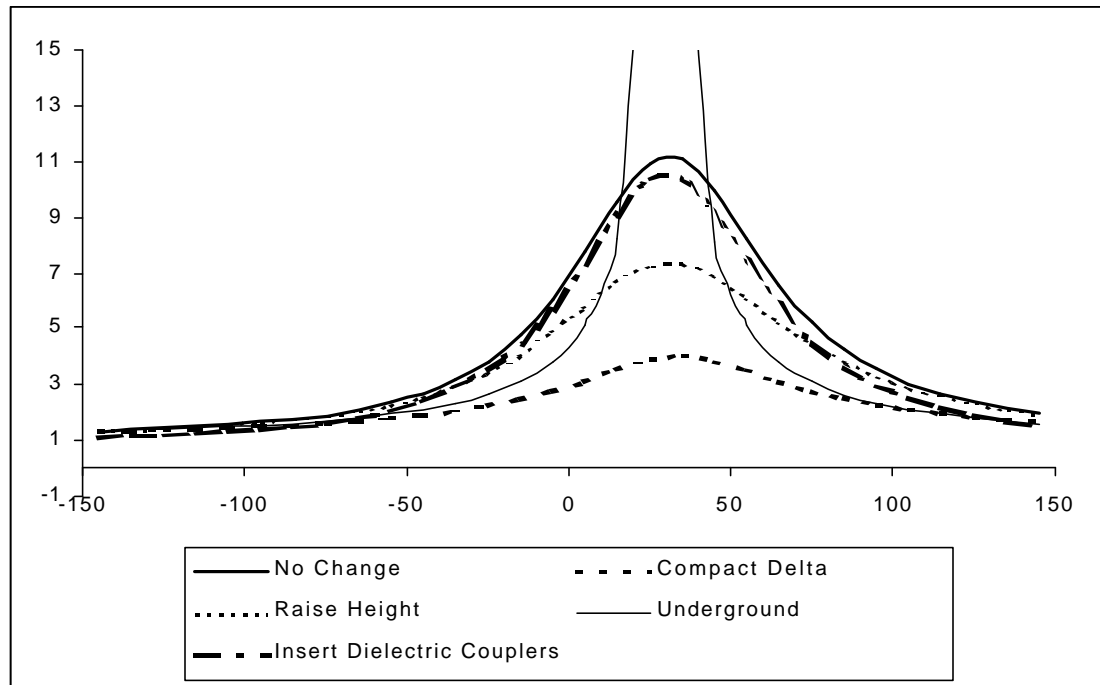


Figure 8.60: Exposure Profile (TWA) for the Distribution Line Retrofit Scenario B (Segment S1)

The exclusion zone in this scenario is set to a total width of 100'. Thus, the exposed population is at least 50' from the line. The corresponding exposure reduction (taking the Horizontal Post configuration as the standard of comparison) as calculated in the ANALYTICA[®] model is shown in Table 8.47.

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**Table 8.48: Relative Exposure Reduction for the
Distribution Line Retrofit Scenario A**

Alternatives	Effects Functions						
	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
No Change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Compact DELTA - All	51.59%	59.50%	78.91%	86.89%	49.85%	75.48%	85.57%
Raise Height - All	14.94%	18.42%	36.39%	61.91%	9.77%	29.98%	58.33%
Underground - All	42.54%	46.91%	58.34%	55.05%	41.68%	57.43%	55.50%
Insert Dielectric Couplers - All	16.41%	19.21%	22.88%	33.09%	17.13%	20.40%	29.66%
Compact Delta - Segment	21.93%	26.14%	43.83%	62.75%	17.56%	38.84%	60.08%
Raise Height - Segment	6.17%	7.13%	18.58%	43.70%	1.61%	12.76%	39.59%
Underground - Segment	18.05%	20.84%	33.80%	43.29%	14.84%	30.76%	42.04%
Insert Dielectric Couplers - Segment	10.07%	12.75%	18.24%	32.47%	9.55%	14.97%	28.95%

Overall Results

The equivalent costs of the major non-EMF criteria are shown in Tables 8.49 and 8.50. Table 8.49 shows the discounted and financed case, Table 8.50 shows the discounted and unfinanced case.

Table 8.49: Equivalent Cost for the Distribution Line Retrofit Scenario B
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Cost	Outages	Property Values	Other	Total
No Change	\$656,500	\$348,500	\$0	\$101,800	\$1,106,800
Compact DELTA - All	\$937,400	\$348,500	\$0	\$102,000	\$1,387,900
Raise Height - All	\$1,327,000	\$348,500	\$0	\$102,100	\$1,777,600
Underground - All	\$7,155,000	\$254,800	-\$3,000,000	-\$59,910	\$4,349,890
Insert Dielectric Couplers - All	\$753,300	\$348,500	\$0	\$102,000	\$1,203,800
Compact Delta - Segment	\$726,700	\$348,500	\$0	\$101,800	\$1,177,000
Raise Height - Segment	\$824,000	\$348,500	\$0	\$101,900	\$1,274,400
Underground - Segment	\$2,301,000	\$325,100	-\$750,000	\$61,380	\$1,937,480
Insert Dielectric Couplers - Segment	\$680,700	\$348,500	\$0	\$101,800	\$1,131,000

Table 8.50: Equivalent Cost for the 115kV New Transmission Line Scenario B
(3% Discount Rate, TPC not Financed)

Alternatives	Cost	Outages	Property Values	Other	Total
No Change	\$656,500	\$348,500	\$0	\$101,800	\$1,106,800
Compact DELTA - All	\$798,200	\$348,500	\$0	\$102,000	\$1,248,700
Raise Height - All	\$994,500	\$348,500	\$0	\$102,100	\$1,445,100
Underground - All	\$4,011,000	\$254,800	-\$3,000,000	-\$59,910	\$1,205,890
Insert Dielectric Couplers - All	\$705,300	\$348,500	\$0	\$102,000	\$1,155,800
Compact Delta - Segment	\$691,900	\$348,500	\$0	\$101,800	\$1,142,200
Raise Height - Segment	\$741,000	\$348,500	\$0	\$101,900	\$1,191,400
Underground - Segment	\$1,515,000	\$325,100	-\$750,000	\$61,380	\$1,151,480
Insert Dielectric Couplers - Segment	\$668,700	\$348,500	\$0	\$101,800	\$1,119,000

Sensitivity Analyses

Figure 8.61 shows the results of this two-way sensitivity analysis assuming that 80% of the total project costs are financed at a 10% annual interest rate. The “No Change” alternative is preferred for fairly low values of p and RR, followed by the alternatives “Dielectric Coupling – Segment” and “Compact Delta – Segment.” However, for most of the p -RR region, the alternative “Compact Delta – All” is preferred.

Figure 8.62 shows the same sensitivity analysis, when TPC is not financed. The pattern is very similar to the financed scenario, except that now the alternative to underground the whole line is favored for a small slice of the region.

Figures 8.63 and 8.64 show the same results considering leukemia only. In Figure 8.61 the alternative “Compact Delta – Segment” is preferred for most p -RR values. In Figure 8.62, undergrounding the whole line is preferred for most values.

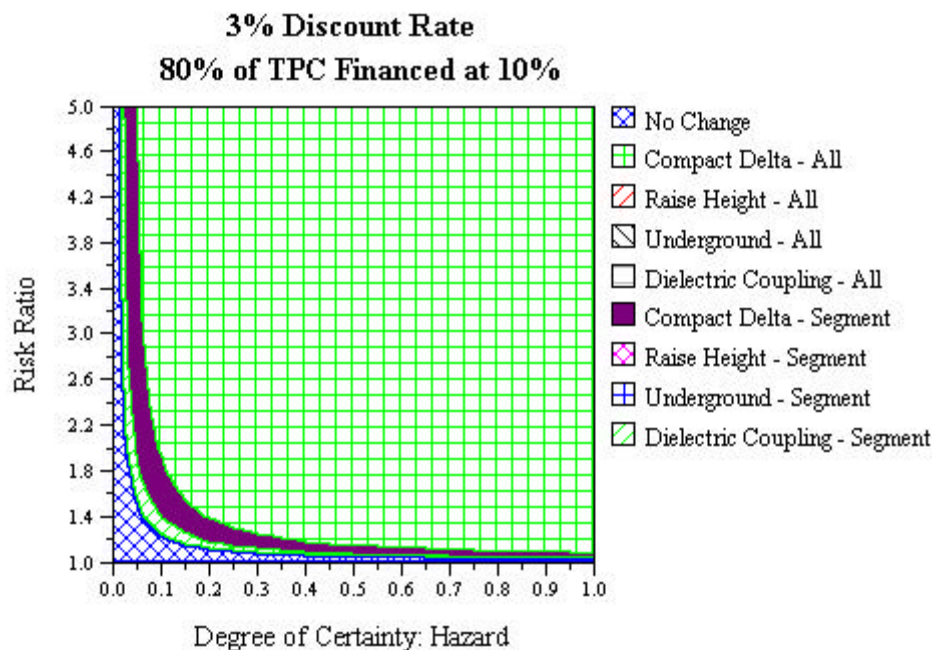


Figure 8.61: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certaty for the Distribution Line Retrofit Scenario A
(All Health Endpoints, TPC Financed, Property Values Included)

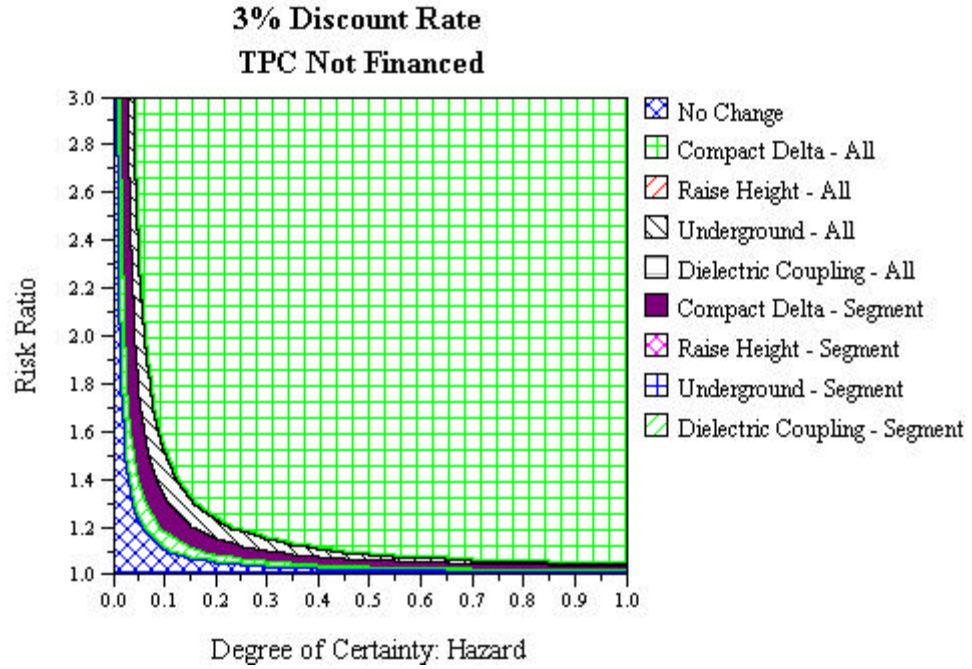


Figure 8.62: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Distribution Line Retrofit Scenario A
(All Health Endpoints, TPC Not Financed, Property Values Included)

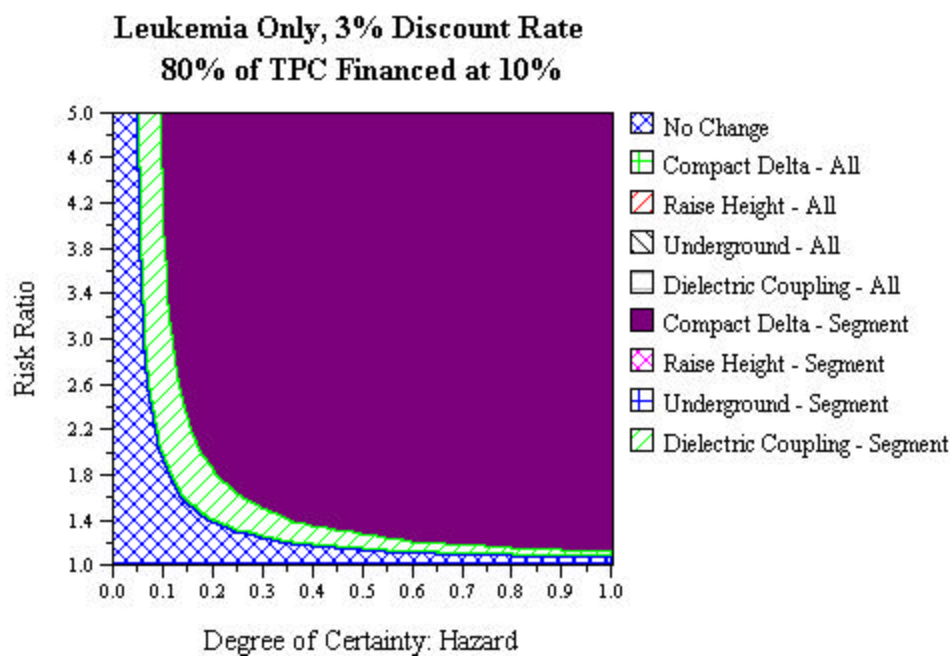


Figure 8.63: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Distribution Line Retrofit Scenario A
(Leukemia Only, TPC Financed, Property Values Included)

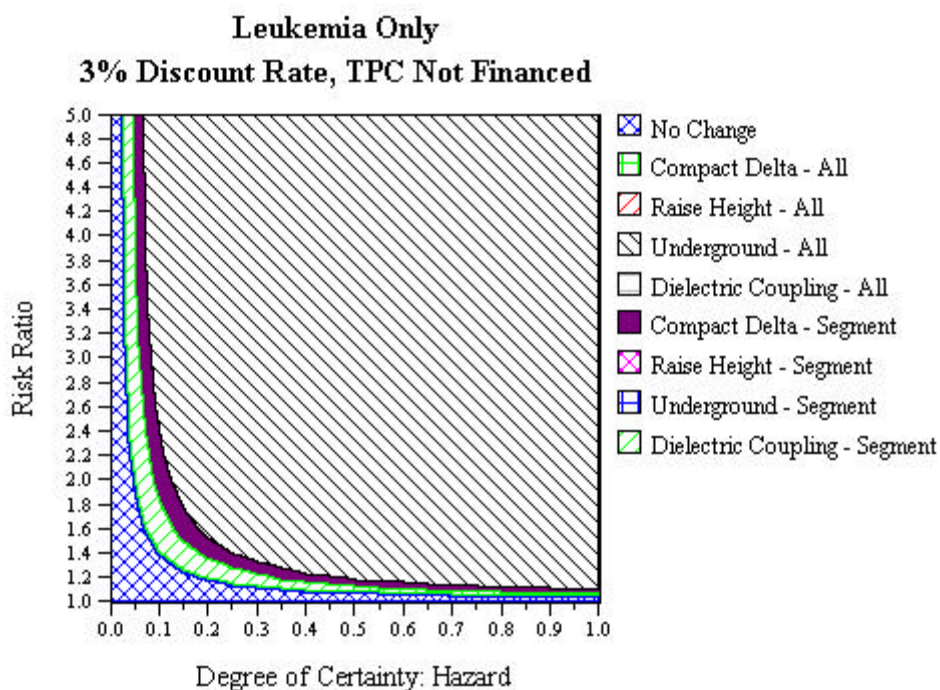


Figure 8.64: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Distribution Line Retrofit Scenario A
(Leukemia Only, TPC Not Financed, Property Values Included)

An Illustrative Analysis Including EMF Health Effects

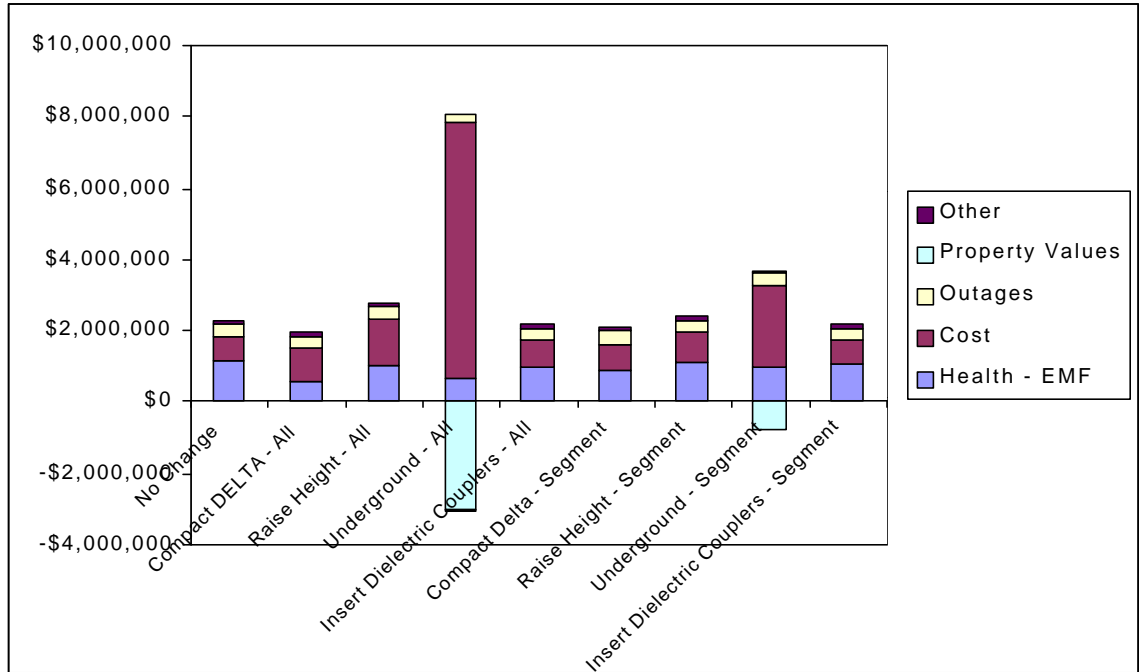
For illustration of specific results including EMF health effects, we chose $p=0.10$ and $RR=2$. Table 8.51 shows the equivalent costs of the major criteria including EMF health assuming that TPC is financed. Figure 8.65 shows the same information as a stacked bar chart. Table 8.52 and Figure 8.66 are the corresponding results assuming that TPC is not financed. When financing TPC, the alternative “Compact Delta – All” has the lowest cost. Without financing TPC, the undergrounding alternative (all) has the lowest cost.

Table 8.51: Equivalent Cost for the Distribution Line Retrofit Scenario B
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
No Change	\$1,180,000	\$656,500	\$348,500	\$0	\$101,800	\$2,287,000
Compact DELTA - All	\$571,400	\$937,400	\$348,500	\$0	\$102,000	\$1,959,000
Raise Height - All	\$1,004,000	\$1,327,000	\$348,500	\$0	\$102,100	\$2,781,000
Underground - All	\$678,200	\$7,155,000	\$254,800	-\$3,000,000	-\$59,910	\$5,028,000
Insert Dielectric Couplers - All	\$986,600	\$753,300	\$348,500	\$0	\$102,000	\$2,190,000
Compact Delta - Segment	\$921,400	\$726,700	\$348,500	\$0	\$101,800	\$2,098,000
Raise Height - Segment	\$1,107,000	\$824,000	\$348,500	\$0	\$101,900	\$2,382,000
Underground - Segment	\$967,300	\$2,301,000	\$325,100	-\$750,000	\$61,380	\$2,905,000
Insert Dielectric Couplers - Segment	\$1,061,000	\$680,700	\$348,500	\$0	\$101,800	\$2,192,000

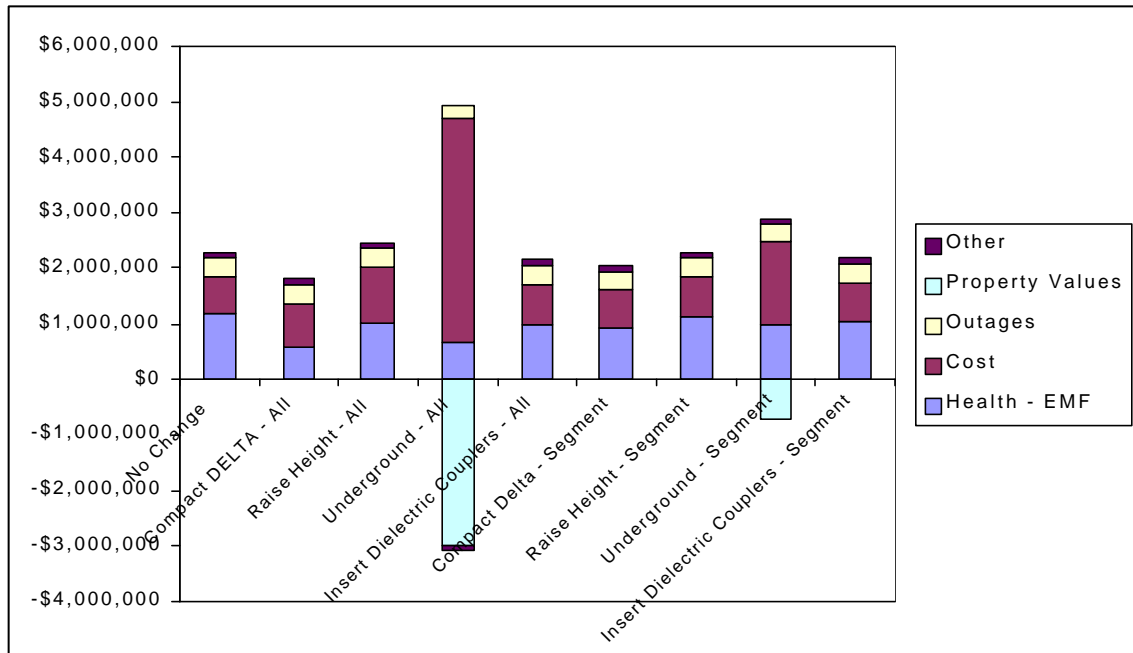
Table 8.51: Equivalent Cost for the Distribution Line Retrofit Scenario B
(3% Discount Rate, TPC Not Financed)

Alternatives	Health - EMF	Cost	Outages	Property Values	Other	Total
No Change	\$1,180,000	\$656,500	\$348,500	\$0	\$101,800	\$2,287,000
Compact DELTA - All	\$571,400	\$798,200	\$348,500	\$0	\$102,000	\$1,820,000
Raise Height - All	\$1,004,000	\$994,500	\$348,500	\$0	\$102,100	\$2,449,000
Underground - All	\$678,200	\$4,011,000	\$254,800	-\$3,000,000	-\$59,910	\$1,884,000
Insert Dielectric Couplers - All	\$986,600	\$705,300	\$348,500	\$0	\$102,000	\$2,142,000
Compact Delta - Segment	\$921,400	\$691,900	\$348,500	\$0	\$101,800	\$2,064,000
Raise Height - Segment	\$1,107,000	\$741,000	\$348,500	\$0	\$101,900	\$2,299,000
Underground - Segment	\$967,300	\$1,515,000	\$325,100	-\$750,000	\$61,380	\$2,119,000
Insert Dielectric Couplers - Segment	\$1,061,000	\$668,700	\$348,500	\$0	\$101,800	\$2,181,000



**Figure 8.65: Stacked Bar Chart of Equivalent Cost Components
for the Distribution Line Retrofit Scenario B**
(3% Discount Rate, 80% of TPC Financed at 10%)

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**Figure 8.66: Stacked Bar Chart of Equivalent Cost Components
for Distribution Line Retrofit Scenario B
(3% Discount Rate, TPC Not Financed)**

8.12 Home Grounding – Scenario A

Note: The detailed model specifications of this scenario can be found in the ANALYTICA® Model named “HOME-A.ana.”

Basic Layout

This scenario describes the analysis of home grounding currents and their mitigation for single-story houses. Within this scenario, the user can choose between different house sizes (1,000 to 3,000 sqft.) and whether the utilities (electricity and water) are on the same or on opposite sides of the home. The homes are assumed to have a square footprint. As a default, the model assumes that the house is occupied by 2 adults (one of which is female) and two children, but no person is assumed be older than 65. These assumptions can be changed.

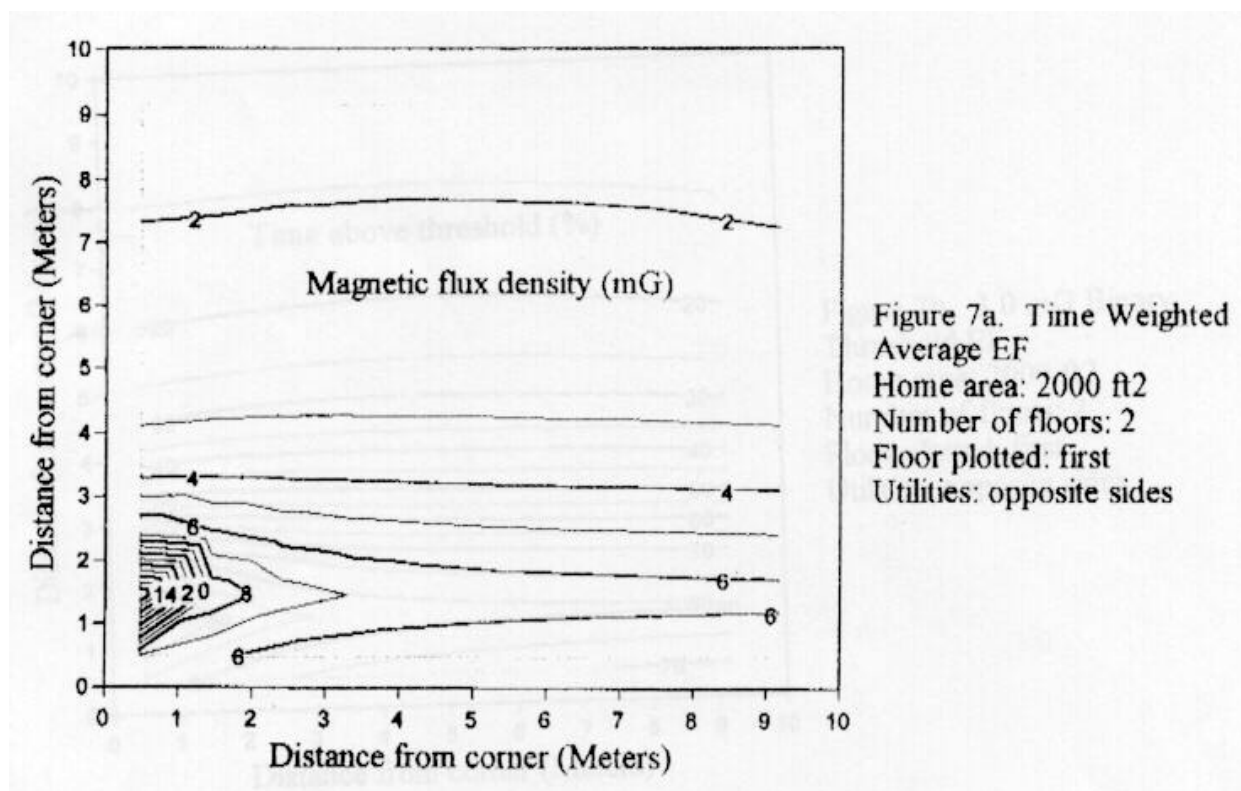
This section describes the case of a 2,000 sqft. home with utilities on opposite sides. Four different mitigation alternatives are considered:

- Insulate Water Pipe
- Improve the Net Return
- Change Living Arrangements (avoid high-exposure areas in the house)
- Do Nothing

Eposure and Exposure Reduction

The exposure data were generated using Jack Adams’ exposure simulation software for a three-dimensional model of the house. Exposures were calculated for the entire area of the house. The default metric is TWA. Figure 8.68 shows an example of the exposure contours using TWA.

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2 **Figure 8.68: Exposure Contours (TWA) for Home Grounding Scenario A**

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4 The relative exposure reductions (taking “Doing Nothing” as the standard of
5 comparison) as calculated in the ANALYTICA[®] model is shown in Table 8.60. for each
6 of the potential exposure metrics.

7

8 **Table 8.54: Relative Exposure Reduction for Home Grounding Scenario A**

Alternatives	Exposure Measures						
	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
Insulate Pipe	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Improve Net Return	60.00%	65.54%	78.79%	90.67%	56.78%	73.34%	90.19%
Change Living Arrangements	10.00%	12.31%	21.21%	33.33%	6.87%	15.28%	26.17%
Do Nothing	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

1 **Overall Results**

2
3 The cost range of the mitigation alternatives are as follows (see von Winterfeldt
4 and Trauger, 1996; Gray, 2000):

Table 8.55: Cost Range for Retrofitting the Home Grounding Scenario A

	Low	High
5 Insulate the pipe	\$200	\$500
6 Improve Net Return	\$150	\$300
7 Change Living Arrangements	\$ 50	\$100
8 Do Nothing	\$ 0	\$ 0

10 **Sensitivity Analyses**

11 Figure 8.69 shows the results of this two-way sensitivity analysis for the high cost
12 of retrofitting, Figure 8.70 shows the same sensitivity analysis for the low cost of
13 retrofitting. The results are similar in both cases: For low values of p and RR, the
14 alternative “Do Nothing” is preferred, for higher values, the alternative “Insulate the
15 Pipe” is preferred. Improving the net return and changing the living arrangement is never
16 a preferred alternative. As expected, the switch-over points (from doing nothing to
17 insulating the pipe) are higher (to the north-east of the graph) for the low cost scenario.
18 When considering leukemia only, the switch-over point occur for higher values of p and
19 RR, since there are less health effects (see Figure 8.71 for the high cost scenario).

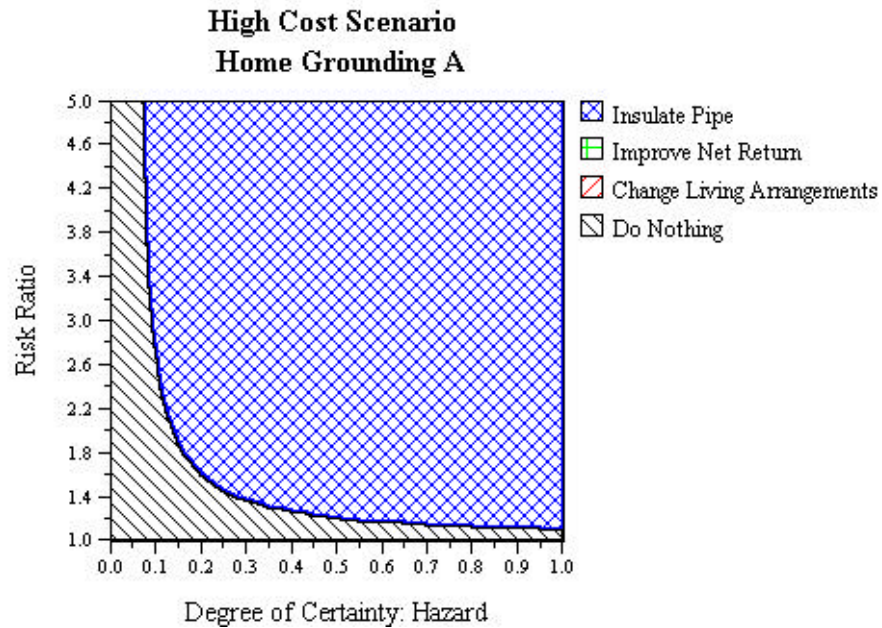


Figure 8.69: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the High Cost Home Grounding Scenario A

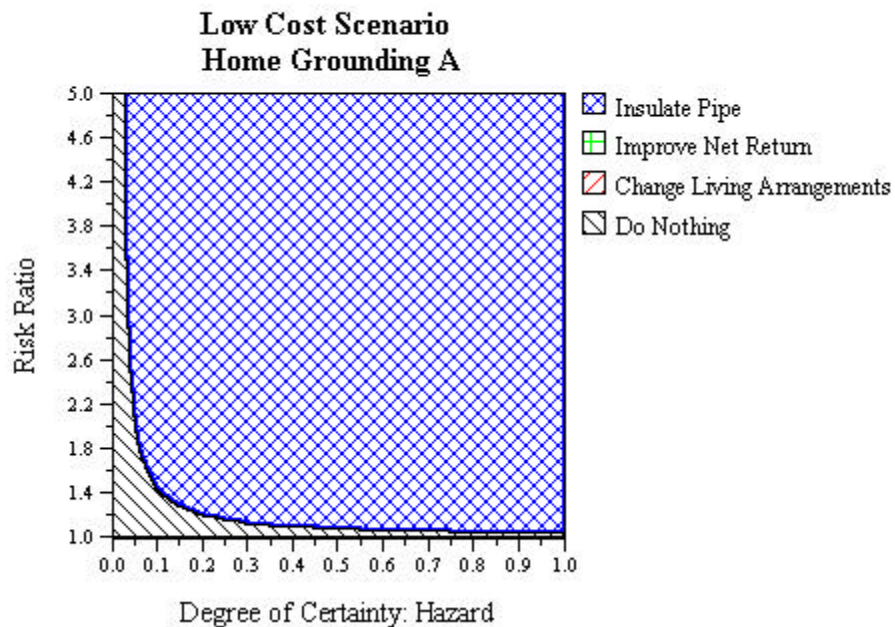
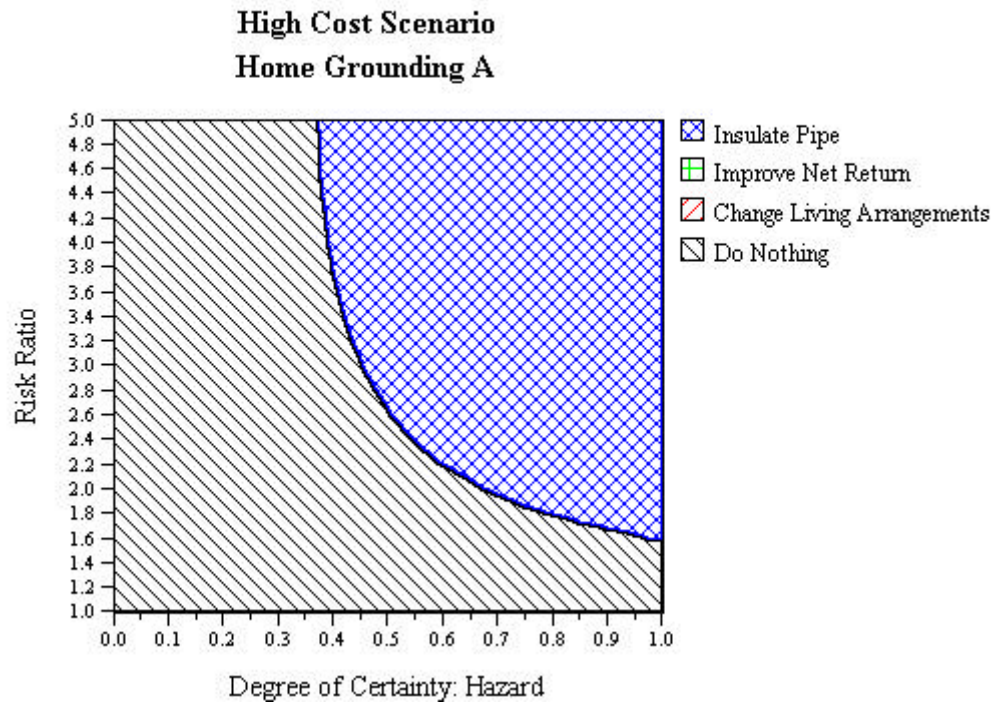


Figure 8.70: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Low Cost Home Grounding Scenario A

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Figure 8.71: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the Low Cost Home Grounding Scenario A

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An Illustrative Analysis Including EMF Health Effects

For illustration of specific results including EMF health effects, we chose $p=0.10$ and $RR=2$. Table 8.56 shows the equivalent costs of the major criteria including EMF health assuming high cost of retrofitting. Figure 8.72 shows the same information as a stacked bar chart. Table 8.57 and Figure 8.73 show the corresponding results assuming low cost of retrofitting.

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Table 8.56: Equivalent Cost for Home Grounding Scenario A (High Cost)

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Alternatives	Health	Cost	Total
Insulate Pipe	\$0	\$500	\$500
Improve Net Return	\$225	\$300	\$525
Change Living Arrangements	\$506	\$100	\$606
Do Nothing	\$562	\$0	\$562

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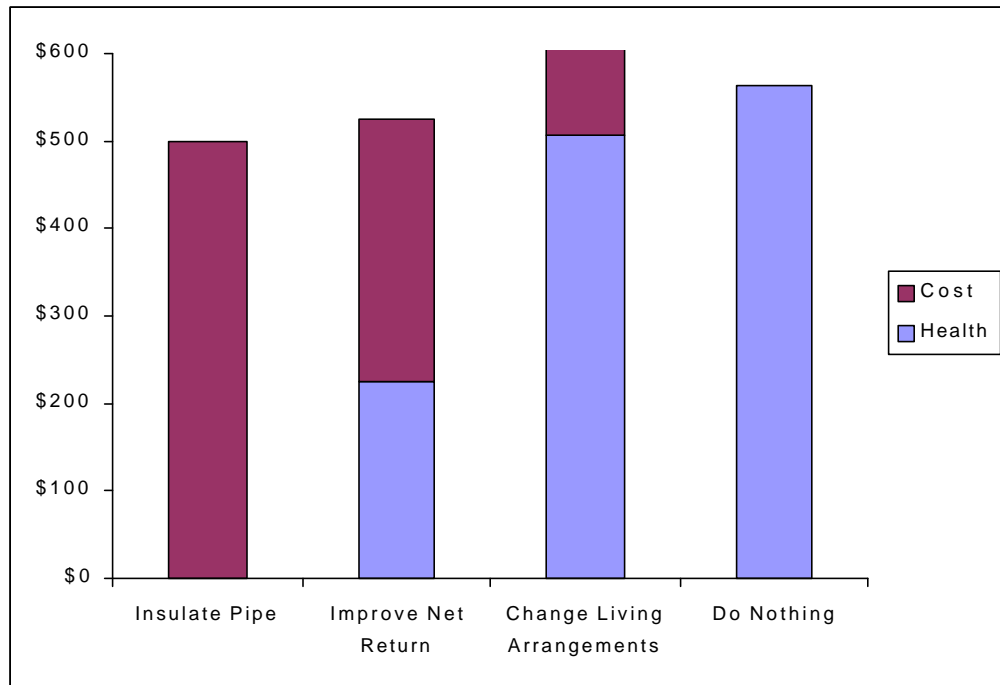
3 **Table 8.57: Equivalent Cost for Home Grounding Scenario B (Low Cost)**

Alternatives	Health	Cost	Total
Insulate Pipe	\$0	\$200	\$200
Improve Net Return	\$225	\$150	\$375
Change Living Arrangements	\$506	\$50	\$556
Do Nothing	\$562	\$0	\$562

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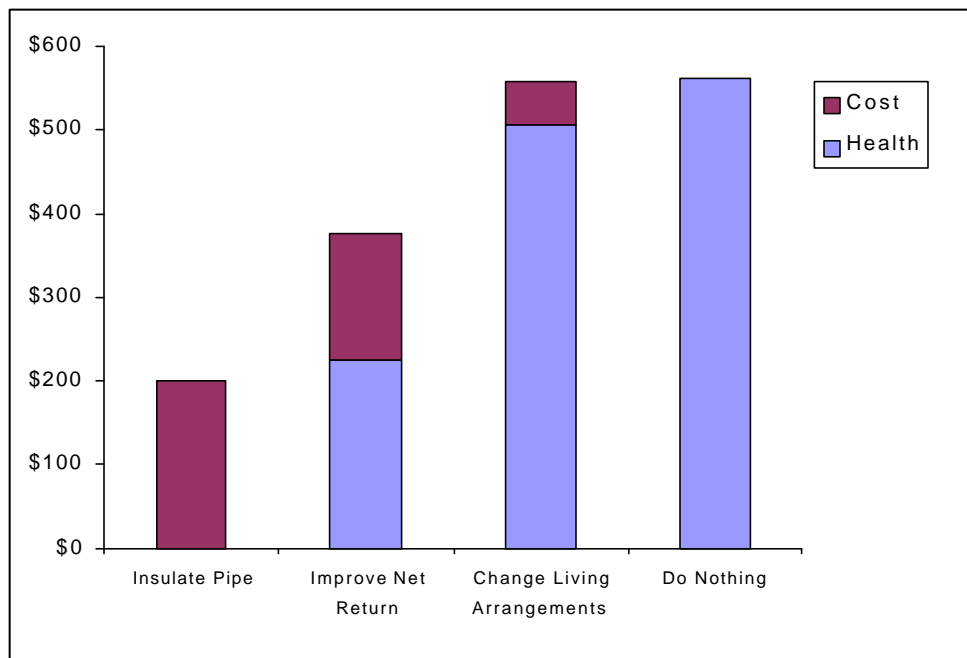
10 **Figure 8.72: Stacked Bar Chart of Equivalent Cost Components**
11 **For the Home Grounding Scenario A (Low Cost)**

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5 **Figure 8.73: Stacked Bar Chart of Equivalent Cost Components**
6 **for the Home Grounding Scenario A (Low Cost)**

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8.13 Home Grounding – Scenario B

Note: The detailed model specifications of this scenario can be found in the ANALYTICA® Model named “HOME-B.ana.”

Basic Layout

This scenario describes the analysis of home grounding currents and their mitigation for two-story houses. Within this scenario, the user can choose between different house sizes (1,000 to 3,000 sqft.) and whether the utilities (electricity and water) are on the same or on opposite sides of the home. The homes are assumed to have a square footprint. As a default, the model assumes that the house is occupied by 2 adults (one of which is female) and two children, but no person is assumed be older than 65. These assumptions can be changed.

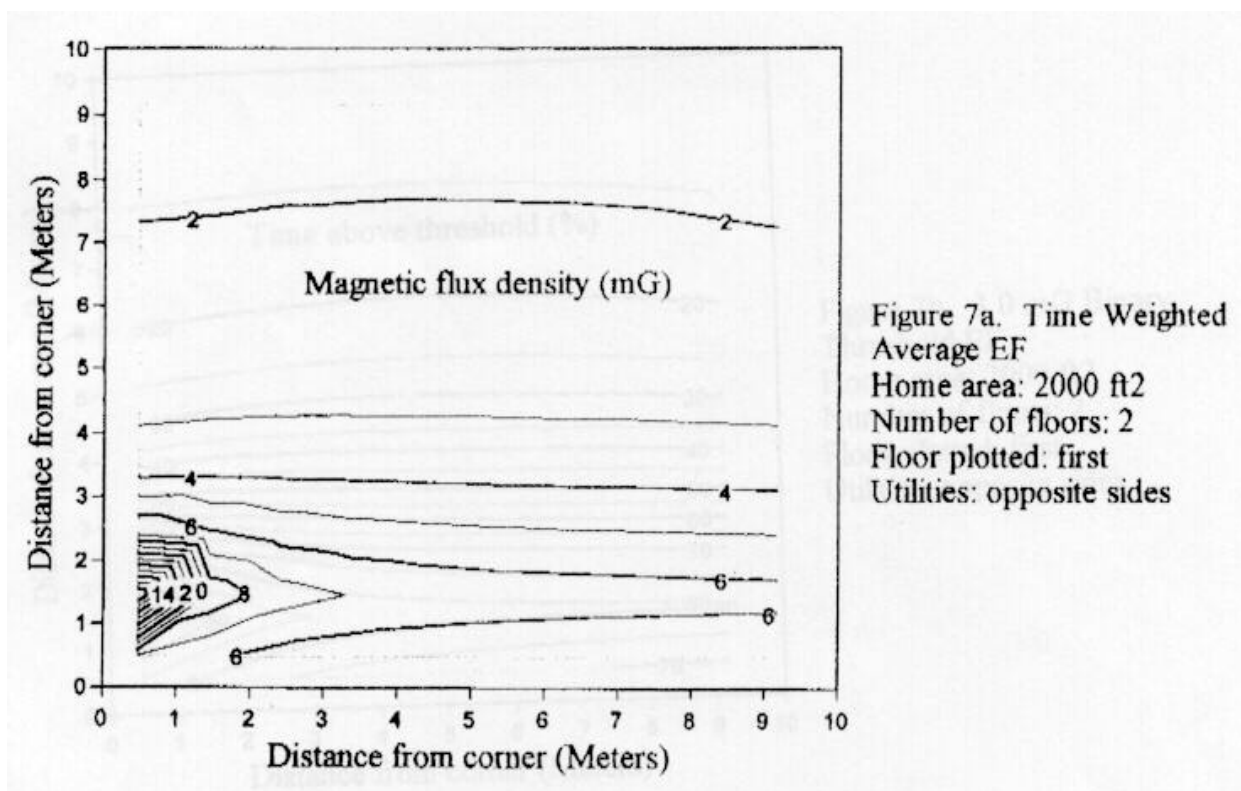
This section assumes a 2,000 sqft. home with utilities on opposite sides. Four different mitigation alternatives are considered:

- Insulate Water Pipe
- Improve the Net Return
- Change Living Arrangements (avoid high-exposure areas in the house)
- Do Nothing.

Exposure and Exposure Reduction

The exposure data were generated using Jack Adams’ exposure simulation software with a three-dimensional model of the house. Exposures were calculated for the entire area of the house. By default, the model runs assume a TWA metric. Figure 8.74 shows an example of the exposure contours using TWA.

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2 **Figure 8.74: Exposure Contours (TWA) for Home Grounding Scenario B**

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4 The relative exposure reductions (taking “Doing Nothing” as the standard of comparison)
 5 as calculated in the ANALYTICA[®] model is shown in Table 8.63. for each of the potential
 6 exposure measures.

7 **Table 8.58: Relative Exposure Reduction for Home Grounding Scenario B**

Alternatives	Exposure Measures						
	TWA	LT-2	LT-5	LT-10	BT-2	BT-5	BT-10
Insulate Pipe	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Improve Net Return	60.80%	67.06%	75.94%	86.00%	61.09%	71.88%	83.53%
Change Living Arrangements	12.00%	14.71%	25.00%	40.00%	6.46%	18.56%	32.35%
Do Nothing	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

1 ***Overall Results***

2

3 The cost range of the mitigation alternatives are as follows (see von Winterfeldt
4 and Trauger, 1996; Gray, 2000):

Table 8.59: Cost Range for Retrofitting the Home Grounding Scenario B

5		Low	High
6	Insulate the pipe	\$200	\$500
7	Improve Net Return	\$150	\$300
8	Change Living Arrangements	\$ 50	\$100
9	Do Nothing	\$ 0	\$ 0

10

Sensitivity Analyses

Figure 8.75 shows the results of this two-way sensitivity analysis for the high cost of retrofitting, Figure 8.76 shows the same sensitivity analysis for the low cost of retrofitting. The results are similar in both cases: For low values of p and RR , the alternative “Do Nothing” is preferred, for higher values, the alternative “Insulate the Pipe” is preferred. Improving the net return and changing the living arrangement is never a preferred alternative. As expected, the switch-over points (from doing nothing to insulating the pipe) are higher (to the north-east of the graph) for the low cost scenario. When considering leukemia only, the switch-over points occur at somewhat higher values of p and RR similar to Figure 8.71.

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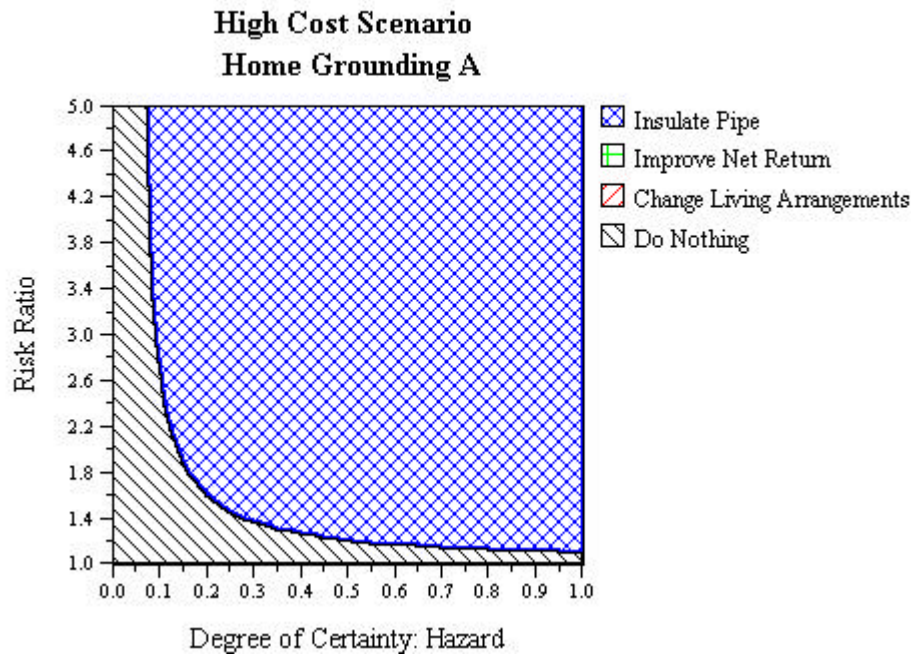
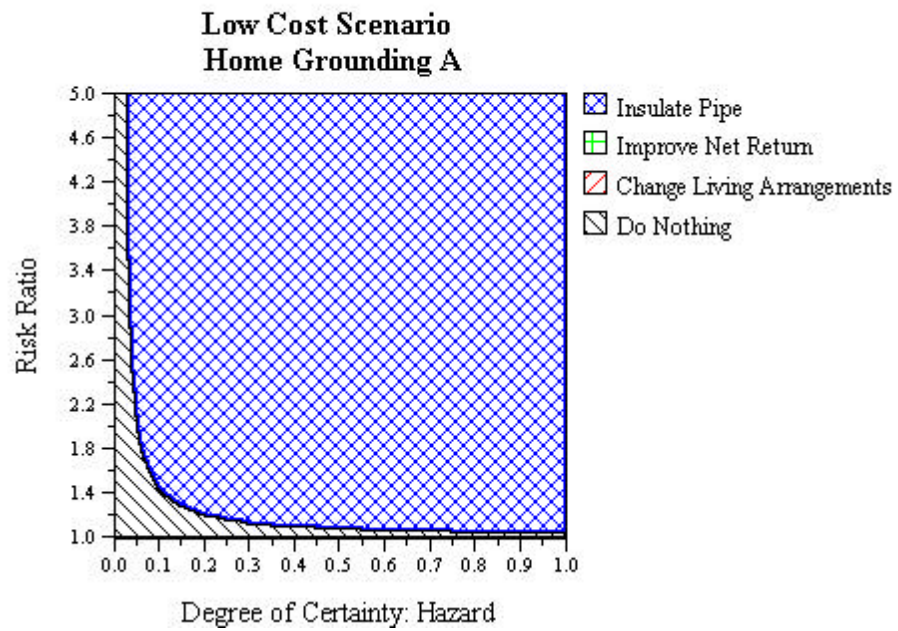


Figure 8.75: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for the High Cost Home Grounding Scenario B



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2 **Figure 8.76: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of**
 3 **Certainty for the Low Cost Home Grounding Scenario B**

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An Illustrative Analysis Including EMF Health Effects

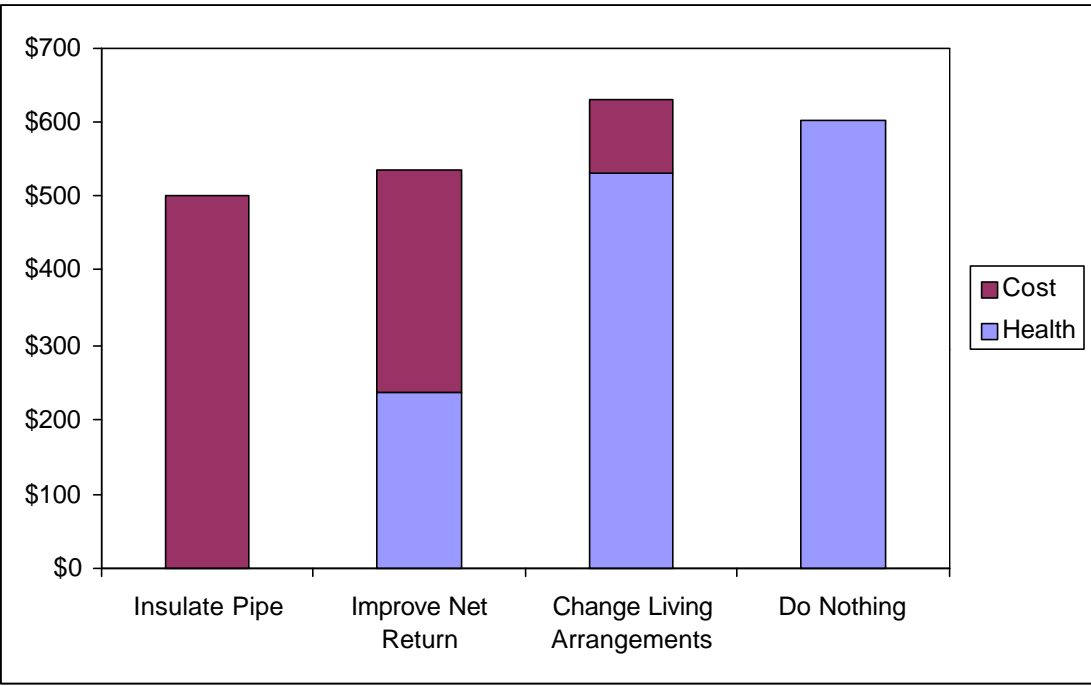
For illustration of specific results including EMF health effects, we chose $p=0.10$ and $RR=2$. Table 8.60 shows the equivalent costs of the major criteria including EMF health assuming high cost of retrofitting. Figure 8.77 shows the same information as a stacked bar chart. Table 8.61 and Figure 8.78 show the corresponding results assuming low cost of retrofitting.

Table 8.60: Equivalent Cost of Retrofitting a Home Grounding Scenario B (High Cost)

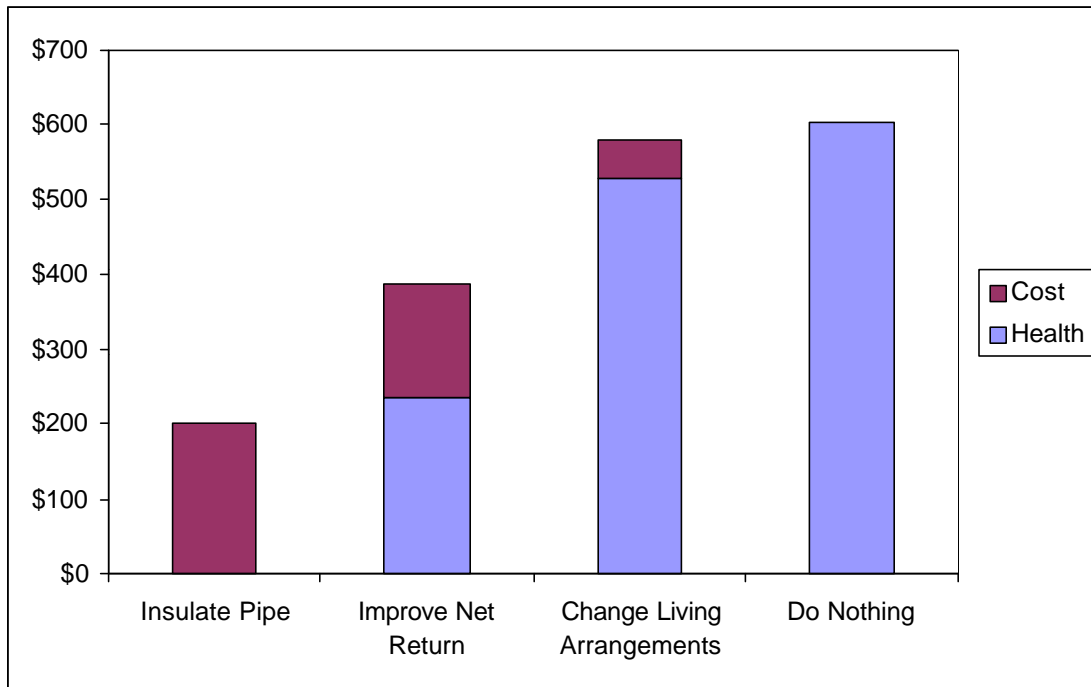
Alternatives	Health	Cost	Total
Insulate Pipe	\$0	\$500	\$210
Improve Net Return	\$236	\$300	\$404
Change Living Arrangements	\$530	\$100	\$580
Do Nothing	\$603	\$0	\$603

Table 8.61: Equivalent Cost of Retrofitting a Home Grounding Scenario B (Low Cost)

Alternatives	Health	Cost	Total
Insulate Pipe	\$0	\$500	\$210
Improve Net Return	\$236	\$300	\$404
Change Living Arrangements	\$530	\$100	\$580
Do Nothing	\$603	\$0	\$603



**Figure 8.77: Stacked Bar Chart of Equivalent Cost Components
For the Home Grounding Scenario B (High Cost)**



**Figure 8.78: Stacked Bar Chart of Equivalent Cost Components
For the Home Grounding Scenario B (Low Cost)**